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TROPICAL PROPAGATION RESEARCH (U)

FINAL REPORT, VOLUME II

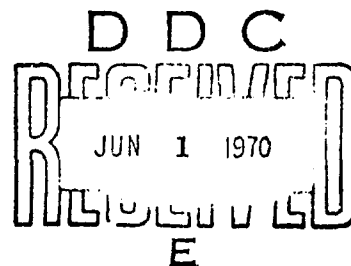
Prepared by

John J. Hicks
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Submitted to

U. S. ARMY ELECTRONICS COMMAND
Fort Monmouth, New Jersey

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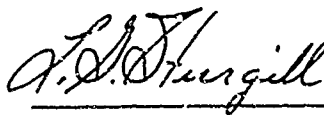
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ABSTRACT

This Final Report Volume II is sequential to Final Report Volume I, which covered an extensive series of radio propagation measurements in a wet-dry (monsoon) tropical jungle in Central Thailand. In contrast, Volume II presents results of measurements in a tropical rain forest area in Southern Thailand. Radio path loss measurements have been conducted in the rain-forest area at frequencies from 2 to 400 MHz, for antenna heights above ground from 7 to 120 feet, with both vertically and horizontally polarized transmitting antennas, and at a large variety of path ranges and configurations in the jungle vegetation. Also, this report includes results from jungle-to-air measurements at frequencies of 25, 50, 100, 250 and 400 MHz, generally with aircraft altitudes of about 500 feet. The results from a series of ground-to-ground measurements for paths of mixed proportions of forest and clearing are presented, along with a theoretical model for this type of propagation path. Finally, an attempt is made to summarize the general conclusions which can be drawn from the work thus far, and which may be useful to a wide variety of communications problems in tropical jungle environments.

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1. INTRODUCTION

This report presents results from an extensive experimental and analytical program on the propagation of radio waves in tropical jungle environments. The over-all objective of this program is to obtain and analyze information that will be generally useful to improvements in the development, design, and deployment of tactical communications systems for such environments. The results of the work are intended to be applicable to systems now available, as well as systems to be developed in the future.

This program is conducted under a contract with the U.S. Army Electronics Command, Fort Monmouth, New Jersey, and is sponsored by the Advanced Research Projects Agency of the Department of Defense. The experimental work is being carried out in Thailand in coordination with the Joint Thai-U.S. Military Research and Development Center (MRDC).

This Final Report, Volume II is sequential to Volume I, which included all of the experimental measurements conducted in a wet-dry tropical jungle (monsoon tropical climate) some eighty miles north of Bangkok. This area of jungle has been previously identified as Area I. This Final Report, Volume II is concerned with measurements in a tropical rain forest area (rainy, tropical climate) in Southern Thailand, which has been identified as Area II. The concept of obtaining a large experimental data base in a wet-dry tropical jungle and then conducting similar measurements in a tropical rain forest is a fundamental element of the project plan. By comparing and analyzing these two sets of data considerable knowledge on the influence of the jungle environment upon the performance of tactical radio systems can be extracted.

The phase of work included in this report begins with the radio propagation loss measurements in Area II and concludes with special jungle-to-air and mixed path measurements in this environment. The experimental and analytical work following this phase will be presented in Final Report, Volume III. Many detailed results from Area II measurements have been given in semiannual reports 9 through 11, and the reader is urged to refer to these for clarification of some of the work summarized herein.

This report concentrates on an extensive comparison of the data from Areas I and II, which appears in Section 3. The results of the jungle-to-air propagation measurements are given in Section 4, and Section 5 is devoted to the mixed-path measurements. Finally, the more important and general conclusions drawn from the work thus far are summarized in Section 6.

2. GENERAL BACKGROUND

The Tropical Propagation Research Program is fundamentally concerned with the communications problems encountered by small unit tactical operations in a tropical environment, as a result of environmental influences on the propagation of signals between the system terminals. Such operations very often must be conducted in areas where jungle vegetation, or forests, constitute a significant element of the environment. Hence, to improve the operations of available communications equipment and the development and design of future equipment, an understanding of the many ways in which jungle terrain influences propagation is essential.

Stated differently, what is needed is the ability to predict the performance of tactical communications systems in tropical vegetated areas having different environmental characters. To fulfill this need, models must be developed which will predict system performance for a given set of parameters associated with the environment. Because of the random character of the environmental elements, and the complex interactions of the environment with the radio wave propagation phenomena, such a model cannot be obtained by theoretical means alone. Rather, it is necessary to develop models through experimental measurements under actual environmental conditions. After the data are obtained and analyzed, various theoretical models can be tested against the data for validity. It is through this continuous interplay between experimental and theoretical results that progress in advancing the state of knowledge of communications in tropical environments is obtained.

The Tropical Propagation Program has followed a carefully laid out plan that is based on the idea that different

types of tropical environments can be classified in a systematic manner by means of a set of quantitative parameters associated with such attributes as topographical roughness, quantity and distribution of vegetation, climate, etc. The experimental effort in Thailand has included careful physical measurements from which these parameters can be derived, and then correlated with the results from propagation measurements taken in the same area. The simultaneous gathering of a complete data base on the test environment itself and the propagation measurements serves two important purposes. First, it precludes the necessity for repeating the work in the future for some other governmental needs. Second, it opens the way to extrapolating the results to other environments, even though it may not be a simple linear process.

In accord with such a plan extensive propagation and environmental measurements were first conducted in the thirty miles square Area I. The forest is classified as "semidry, evergreen," and is quite similar to most of the "jungle" areas in South Vietnam. The geographical location of Area I is shown in Figure 2.1.

The results of the work in Area I, covering the frequency range of 0.1 MHz to 10 GHz, have been presented in semiannual reports 1 through 7, and summarized in Final Report Volume I. Perhaps the most important finding from analysis of the data from Area I was that the slope of the median electric field strength versus distance was significantly steeper at distances below 0.3 miles from the transmitting antenna than from 0.3 miles to 3.0 miles and beyond. It was also noted that this later slope was only slightly greater than an inverse distance slope. These observations suggested that, beyond some nominal distance from the transmitting antenna, wave propagation

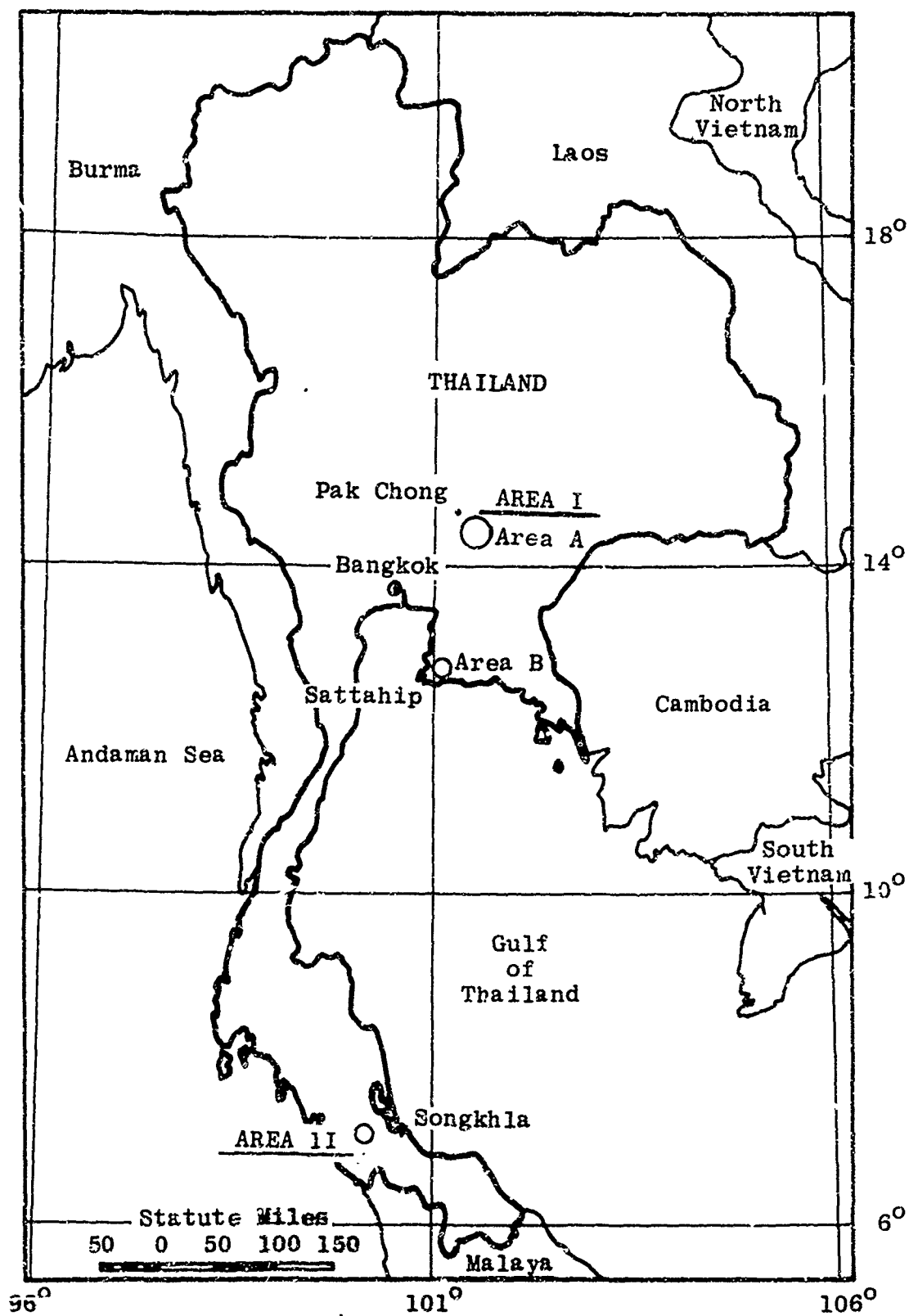


Figure 2.1 Locations of Thailand Test Areas

in jungle areas occurred principally along the tree-top and air boundary. Hence, in Semiannual Report No. 4, it was postulated that the signal path in jungle areas would generally be one of "up, across, and down," with the signal passing through vegetation only in the vicinity of the transmitting and receiving antenna.

From these experimental findings several significant theoretical works have followed. A conducting slab model for propagation within a jungle medium was developed by D. L. Sachs and P. J. Wyatt [1]. Later, D. L. Sachs [2] compared theoretical results from this model with experimental data, and found fairly close agreement up to about 100 MHz, beyond which the uniform slab model cannot, according to Sachs and Wyatt, reasonably be expected to hold.

Tamir^[3] extended the analysis of the conducting slab model and examined propagation loss for various antenna heights, frequency, and polarization, and also found good agreement with experimental results up to about 100 MHz. Dence and Tamir^[4] further took into account the proximity influence of the ground upon antenna impedance, especially as this relates to very low antennas.

Following the completion of the measurements in Area I the measurement operations were moved to Area II, the general geographical location of which is shown in Figure 2.1. The climate in this area is classed as "rainy," based upon its annual average and monthly distribution, and the forest is classed as virgin "rain forest" on a world-wide geographical scale. As a result of the extensive analysis and findings from the Area I measurements it was possible to significantly reduce the quantity and distance range of the regular ground-to-ground path loss measurements, and reduce the frequency range to

2-250 MHz. This allowed time to devote more measurements to special path configurations, such as jungle-to-air and mixed path configurations. It is, however, the 2-250 MHz, ground-to-ground, data base which is compared in detail with the corresponding data base from Area I.

As mentioned earlier, an important element of the measurement plan involves measuring the physical attributes of the environment, such as the mass and dimensional statistics of the jungle vegetation. In Area I the forest survey to obtain this data was conducted by the Environmental Sciences Division of MRDC, using more or less normal methods for forest mensuration. With these procedures the normal sample plot size is 10 X 40 meters (113 X 33 feet), the locations of the plots presumably randomly distributed over the entire area to be characterized. Within each sample plot, sets of measurements were made of tree heights, diameters at breast height, nearest neighbor distances, etc. The statistical characterization of an entire forest area is then obtained by combining the data from the several randomly located plots. The detailed results of such a survey for Area I were reported in Semiannual Report No. 6, and these results appear to be statistically consistent with what one would observe visually.

However, the data obtained from the MRDC measurements in Area II did not yield statistically consistent results. For example, there was too great a variance in the tree heights and diameters at breast height from one sample plot to another, which did not agree with what visually appeared to be a more 'homogeneous' forest. Furthermore, there were not quite enough sample plots measured within the test area to statistically characterize this area by itself.

The large variances between the sample plots could possibly be explained in several different ways, but one that deserves mention here is the influence of errors on the sample plot boundary lines in a rain forest, which contains large trees in relation to the sample plot size. For example, with a sample plot of 40 X 10 meters (113 X 33 feet), if a typically large tree is on or near the boundary line of the sample plot, the decision to include or not include that tree in the sample measurements may affect the biomass of the plot by as much as 100 per cent. This difficulty can be avoided by increasing the size of the individual sample plot to the point where a decision to include or exclude a member near the boundary line will not significantly affect the statistics of the individual plot. By means of measurements in Area II on different sized sample plots, it has been determined that the optimum sample plot size for the specialized needs of radio propagation research is about 200 X 200 feet.

Accordingly, another forest survey will need to be conducted in Area II to obtain data that can be reliably compared with Area I forest data. These measurements have not yet been completed and the data is not available for inclusion in this report.

The above comments do not refute the validity of the results presented in MRDC's report on the statistical description of the forests of Thailand [5]. The methods of sampling and analysis in that excellent work lead to a statistical description of a more composite tropical rain forest in Thailand, the sample plots having been distributed over a much larger geographical area than that of Test Area II. It remains to be determined more exactly just where the characteristics of the rain forest of Area II fit in relation to the composite data in the MRDC report.

Therefore, with the exception of statistical data on the forest characteristics for Area II, all of the major climatological attributes of the environment of Area I and Area II that pertain to radio propagation have been obtained and compared. These results are presented more fully in Final Report, Volume I, and Semiannual Report No. 10. For the convenience of the reader, these results are summarized in condensed form in Table 2.1.

In Area II, supplemental measurements were made at frequencies of 0.5 to 10 GHz. Also, measurements were made to show the effects of relatively low antenna heights. The results of these two series of measurements were presented in Semiannual Report No. 10 and, except in the general conclusions, will not be further discussed here. This report is concerned mainly with the transmission loss measurements in Area II at frequencies of 2 to 250 MHz, with the comparison of these results with those of Area I, with the ground-to-air transmission loss measurements, and with mixed path measurements.

Table 2.1 Climatological Comparison Between Area I and Area II

		<u>Annual Average</u>	<u>Monthly Average</u>	<u>Monthly Median</u>	<u>Standard Deviation</u>
AREA I (Wet-Dry, Tropical)	Temperature ($^{\circ}\text{F}$)	80.7	80.7	81.3	3.5
	Rainfall (in.)	52.6	4.4	2.7	3.8
	Relative Humidity (%)	67.53	57.53	68.2	6.6
	Relative Refractive Index (K)	1.502	1.502	1.521	0.045
AREA II (Rainy, Tropical)	Temperature ($^{\circ}\text{F}$)	84.2	84.2	84.7	1.4
	Rainfall (in.)	97.2	3.1	6.75	6.5
	Relative Humidity (%)	74.04	74.04	76.0	6.9
	Relative Refractive Index (K)	1.621	1.621	1.620	0.055

3. PROPAGATION IN TWO DIFFERENT JUNGLE ENVIRONMENTS

As discussed previously, the primary purpose of the theoretical and experimental research program on radio propagation in a tropical jungle environment is to obtain and analyze basic propagation and environmental data in a manner which provides knowledge to realize the most efficient use of present short range tactical communications equipment and to aid in the design and development of new equipment. In the course of this program the lateral wave mode, which is the basic mode of propagation in a jungle environment at HF and VHF, the frequencies most important to tactical communications, has been experimentally determined [Jansky & Bailey, 1966] and a theoretical model explaining the phenomena has been developed [Sachs and Wyatt, 1966, 1968; Sachs, 1966]. This model is a conducting slab bounded above by air and below by ground and has been substantiated by Sachs and Wyatt [1966; 1968] and Sachs [1966] at frequencies from 6 to 100 MHz by propagation data from a wet-dry tropical forest near Pak Chong in Northern Thailand. This was the first experimental test area utilized in this program and is referred to as Area I. The environment has been described in detail in preceding semiannual reports, and is briefly discussed in Section 2 of this report.

The slab model provides simple and clear concepts for visualizing the mean transmission loss in forested environments. Its practical utility is limited, however, because it cannot account for the spatial variability in the data [Jansky & Bailey, 1966]. Furthermore, the use of this model requires some knowledge of the physical and electrical parameters associated with the given forest. The first limitation is inherent in the principles of the model, while the latter arises from a

lack of knowledge of the effective electrical constants of the ground and the slab, which depend upon the environment to be represented by the model.

The lack of quantitative knowledge of the environmental influences on jungle propagation was, of course, recognized early, and was a major consideration in originally establishing the research program. It was because of this that, upon completion of measurements in Area I, a second experimental area was established in the characteristically different environment of a tropical rain forest in the Satun district in Southern Thailand. This experimental region is referred to as Area II and its environment is also discussed in Section 2. The most obvious difference in the two areas is that Area II has taller and denser foliage.

The basic propagation experiments have been completed in Area II and a large data base, taken in a manner that permits comparison of the data from the two areas, is now available from each area. The purpose of this section is to present those data, compare the experimental results from the two areas, re-examine the data from Area I for its applicability in the theoretical slab model, examine the data from Area II for its applicability in the slab model, and compare the theoretical slab model results for the two areas, and the relation of these results to the two environments. The results suggest a slight change in the conceptual view of the slab model, based on qualitative considerations of scattering by the trees, which broadens its frequency range of applicability in determining the mean transmission loss. The need and direction of further effort is discussed, especially in relation to scatter phenomena.

The data considered covers a frequency range of 2 to 400 MHz, antenna heights from 12 to 120 feet, and horizontal

and vertical polarization. A theoretical background is briefly presented, followed by experimental procedures, data analysis and discussion and conclusions.

3.1 Theoretical Background

In discussing the data, reference is often made to the uniform conducting slab model of the jungle, and a brief review of its development and governing equations is given here for continuity.

Sachs and Wyatt [1966, 1968] proposed that the jungle may be modeled as a uniform conducting slab bounded above by air and below by the ground. They proposed that this model would be reasonable if:

"(1) The fluctuation in the number of trees, etc., in an area one wavelength squared is small compared with the total number of trees in this area.

"(2) If the height of the jungle is larger than a wavelength it is necessary that within the jungle the average electrical properties do not vary significantly with height.

"(3) The transition region between the air above and the jungle must be small compared with a wavelength."

The first criterion has since been discounted as being too restrictive in a forested environment due to the

inherent averaging of the fields by forward scatter from the trees in the environment which, if the incoherent scatter field is large with respect to the coherent scatter field, gives average results similar to those from a continuum, or slab.* The third criterion also appears to be too restrictive for the same reason. This qualitative scatter concept appears to be a significant factor in ascribing an effective slab height to the jungle and is referred to later.

Sachs and Wyatt [1966, 1968] applied the theoretical concepts of propagation in a layered media developed by Brekhovskikh [1960], Wait [1962], and others, to examine the signal behavior within the conducting slab for a vertically polarized infinitesimal dipole source within the slab, and showed that propagation is principally via the lateral wave. They compared the theoretical results with experimental data from Area I and, by assuming the slab thickness to be the average tree height of Area I and using estimated values of conductivities and dielectric constants of the air, jungle, and ground, obtained reasonable agreement between theory and experiment. It is noted that in employing the data at frequencies of 2, 6 and 12 MHz they apparently assumed the transmitting antenna heights to be equivalent to the lengths of the vertical monopoles. That this is a valid assumption is not obvious and would seem to require some justification, since the antenna height-gain effects are quite important in quantitatively verifying the model.

* Group III paper in Report of Technical Study Group Meeting on Environmental Effects on Short-Range Communication, sponsored by ARPA and ESSA, held at ITSA, Boulder, Colorado, 14-16 March 1967, and prepared under the direction of T. W. Doepfner.

Sachs [1966] later extended the work to include horizontal polarization and antennas outside the slab (above the jungle) for both polarizations. Also, it was known that the jungle medium exhibits less losses for horizontal than vertical polarization [Jansky & Bailey, 1966], and, in apparently the only attempt which has been made to account for this anisotropy, Sachs [1966] assumed different conductivities for the two polarizations to improve agreement between theory and experiment.

Tamir [1967] examined the functional dependence of the various factors involved in the lateral wave theory (frequency, antenna height, electrical constants, etc.) for antennas near the jungle-air interface where the ground effects are negligible and showed that these are consistent with the functional behavior of data from Area I. Dence and Tamir [1969] employed the model to examine the preference for horizontal or vertical polarization for very low antennas in a jungle by including the effect of antenna impedance changes due to ground proximity. Their conclusions are questionable, however, because they assume the jungle anisotropy to be negligible which, as will be shown later, is not generally justified.

Excluding the case of very low antennas, the measurable electric field $|E|$ is given by [Sachs and Wyatt, 1966; Sachs, 1966; Tamir, 1968]

$$|E| = \frac{9 \times 10^{10} \sqrt{\text{Power (Kw)}}}{\sqrt{2} \pi f r^2 |\eta_j^2 - 1|} F(z) F(z_0) \quad \mu\text{V/m} \quad (3.1.1)$$

where f is frequency in MHz, r is range, h is the slab or effective jungle height, z and z_0 are the transmitting and receiving

antenna heights above ground, $\eta^2 = \epsilon + 18 i\sigma/f(\text{MHz})$ is the refractive index, ϵ is the dielectric constant, σ the conductivity in mmhos/m, and the subscript, j , indicates the jungle medium (see sketch below for nomenclature). Further, for both horizontal and vertical polarizations

$$F(z) = e^{-\alpha_L(h-z)} \left| \frac{1 + \Gamma_{V,H} e^{-2k_0 z \sqrt{1 - \eta_j^2}}}{1 - \Gamma_{V,H} e^{-2k_0 \sqrt{1 - \eta_j^2} h}} \right|, \quad 0 < z < h,$$

and for vertical polarization

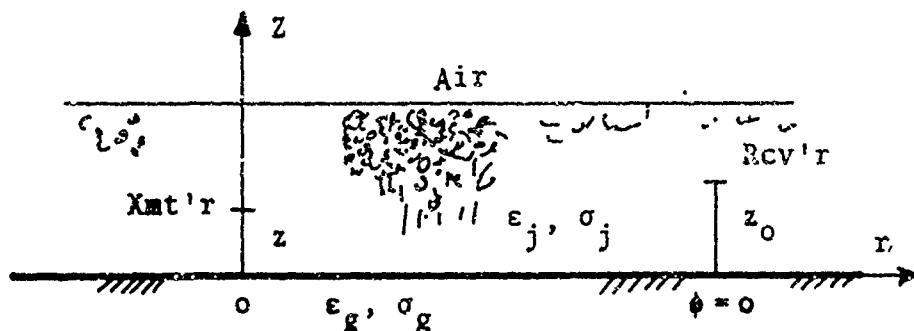
$$F(z) = \left| \frac{(z-h)k_0(1 - \eta_j^2)^{\frac{1}{2}} + \eta^2 \left(\frac{1 + \Gamma_V e^{-2k_0 \sqrt{1 - \eta_j^2} h}}{1 - \Gamma_V e^{-2k_0 \sqrt{1 - \eta_j^2} h}} \right)}{(z-h)k_0(1 - \eta_j^2)^{\frac{1}{2}} + \eta^2} \right|$$

$$\frac{\sqrt{r}}{k_0} > z > h$$

and for horizontal polarization

$$F(z) = \left| \frac{(z-h)k_0(1 - \eta_j^2)^{\frac{1}{2}} + \left(\frac{1 + \Gamma_H e^{-2k_0 h \sqrt{1 - \eta_j^2}}}{1 - \Gamma_H e^{-2k_0 h \sqrt{1 - \eta_j^2}}} \right)}{(z-h)k_0(1 - \eta_j^2)^{\frac{1}{2}} + \left(\frac{1 + \Gamma_H e^{-2k_0 h \sqrt{1 - \eta_j^2}}}{1 - \Gamma_H e^{-2k_0 h \sqrt{1 - \eta_j^2}}} \right)} \right|$$

$$h < z < \sqrt{\frac{r}{k}} + h$$



where $\alpha_L = k_0 \operatorname{Im} (\sqrt{\eta_j^2 - 1})$ and the subscripts V and H correspond to vertical and horizontal polarization respectively. Also, for vertical polarization

$$\Gamma_V = \frac{\eta_g^2 (1 - \eta_j^2)^{\frac{1}{2}} - \eta_j^2 (1 - \eta_g^2)^{\frac{1}{2}}}{\eta_g^2 (1 - \eta_j^2)^{\frac{1}{2}} + \eta_j^2 (1 - \eta_g^2)^{\frac{1}{2}}}$$

and for horizontal polarization

$$\Gamma_H = \frac{(1 - \eta_j^2)^{\frac{1}{2}} - (1 - \eta_g^2)^{\frac{1}{2}}}{(1 - \eta_j^2)^{\frac{1}{2}} + (1 - \eta_g^2)^{\frac{1}{2}}}$$

$F(z_0)$ is the same as $F(z)$ with z replaced by z_0 . The data are in terms of basic transmission loss, L_b , referenced to isotropic antennas, and the theoretical field of Eq. 3.1.1 may be converted to L_b by [Norton, 1959]

$$L_b = 139.36 - 20 \log |E| + 20 \log f \quad (3.1.2)$$

which is derived for 1 Kw of power radiated into free space by an isotropic antenna. Sachs and Wyatt [1966, 1968] and Sachs [1966] show that Eq. 3.1.1 holds for frequencies of approximately 6 to 100 MHz and ranges nominally greater than 0.1 mile. Eqs. 3.1.1 and 3.1.2 will be utilized in comparing the behavior of the theoretical transmission loss with the experimental loss for Areas I and II to obtain equivalent electrical parameters and slab height of the two forested environments.

3.2 Experimental Procedures

The propagation data were measurements of field strength in db above 1 μ volt/m as a function of distance, frequency, antenna heights and polarization for each test area. Table 3.2.1 gives the specific parameters employed at each test area. All antenna heights are referenced to their feed points.

Table 3.2.1
Experimental Parameters for Area I and Area II

<u>Parameter</u>	<u>Area I</u>	<u>Area II</u>
Frequency (MHz)	2, 6, 12, 25, 50, 100, 250, 400	2, 12, 25, 50, 100, 250
Transmitter Antenna Height (Feet)	0, 13, 80, 120	0, 13, 40, 80
Receiver Antenna Height (Feet)	11 to 80	8 to 115
Polarization	Vertical and Horizontal	Vertical and Horizontal
Range (Miles)	.05 to 1.2	.05 to 6

The procedure in each test area was to locate the receiving antenna at a designated field point and measure the field strength continuously as the receive antenna was raised or lowered between the maximum and minimum heights employed. The mean of the maximum and minimum field strength over contiguous 5 - 6 foot increments was recorded and assigned to the heights at the mid-points of the measurement increments. The

measurements conducted at the lowest antenna height were single unaveraged measurements. This procedure was repeated for various combinations of the parameters listed in Table 3.2.1.

Ground based, $\lambda/4$ monopoles (λ = wavelength) were employed for the vertically polarized transmitting antenna at frequencies of 2, 6, and 12 MHz. Resonant $\lambda/2$ dipoles were employed as transmitting antennas at frequencies > 12 MHz for vertical polarization and at all frequencies for horizontal polarization. The receiving antennas for both polarizations were small loops at frequencies of 2, 6, 12, and 25 MHz, and $\lambda/2$ dipoles for frequencies > 25 MHz.

The transmitters and receivers and calibration procedures have been discussed previously [Jansky & Bailey, 1966].

3.3 Data Analysis and Discussion

The field strength measurements were reduced to basic transmission loss L_b for isotropic antennas [Norton, 1959; Jansky & Bailey, 1964]. The resultant L_b includes any losses due to the antennas being near ground or foliage, caused by antenna impedance changes, as well as the loss over the transmission path. The losses due to the antennas being near ground (i.e., impedance changes) are negligible at frequencies > 6 MHz for the antenna heights used. These losses may become significant, however, at 2 MHz for all except the higher antennas [Dence and Tamir, 1969]. The foliage proximity losses are negligible in all cases [Jansky & Bailey, 1965; Dence and Tamir, 1969].

With the aid of a computer, the resultant values of L_b were extrapolated to a range of 1 mile by removing the

anticipated $40 \log r$ range dependence from each value. This extrapolation brings a large number of measurements to a common range which simplifies a critical examination of the transmission loss as a function of antenna height, frequency and polarization, which are directly dependent upon the foliage medium. Note that the range dependence, which has been well established [Jansky & Bailey, 1966] has the same form as that of a surface wave [Jordon, 1950] and thus requires only that the foliage medium provide a surface for supporting the wave. The $40 \log r$ dependence is therefore virtually independent of the internal structure of the foliage medium, and the extrapolation with range is not expected to influence the dependence of transmission loss on frequency, antenna height or polarization. It should be noted, however, that the range of validity of the theoretical expressions for antennas above the slab (Eq. 3.1.1) are frequency, path length and antenna height dependent, and knowledge of the range of validity is obliterated by extrapolation to the range of 1 mile. It is assumed, however, that Eq. 3.1.1 holds in the extrapolated case here, although this is not valid for those data from short distances and frequencies greater than 100 MHz. The mean and standard deviation, σ , of the extrapolated L_p for Areas I and II were then computed for each combination of antenna height, frequency and polarization. The results are given in Tables 3.3.1 to 3.3.8.

To illustrate the loss characteristics of the two environments from a graphic point of view, Figure 3.3.1 is a plot of the experimental mean L_p , extrapolated to one mile, for vertical polarization as a function of frequency and equal transmit and receive antenna height (except for the zero height vertical monopole transmitting antennas at 2, 6 and 12 MHz) for Areas I and II. Figure 3.3.2 is a similar plot for horizontal

Table 3.3.1
Mean Basic Transmission Loss at One Mile in Area I

H_R (Ft.)	Freq. MHz	Horizontal Polarization; $H_T = 13$ Feet				
		<u>25</u>	<u>50</u>	<u>100</u>	<u>250</u>	<u>400</u>
11	104.1	110.4	120.6	140.2	145.5	
20	98.9	105.9	119.3	139.9	145.0	
26	96.5	104.7	119.3	138.5	144.4	
31	95.4	103.8	119.3	136.7	140.7	
37	94.4	103.7	117.1	133.8	140.8	
42	93.7	103.4	114.6	130.7	138.0	
48	93.4	102.8	111.8	128.7	134.0	
53	92.8	101.8	109.8	125.5	132.8	
59	92.1	100.8	108.3	123.1	130.7	
64	91.6	99.6	107.3	122.0	129.8	
69	91.0	98.7	106.2	120.9	126.9	
73	90.6	98.2	105.4	119.6	124.9	
79	89.9	97.5	104.5	118.3	123.9	

Table 3.3.1 (continued)
Mean Basic Transmission Loss at One Mile in Area I

Freq. MHz	Horizontal Polarization; $H_1 = 40$ Feet							
	<u>2</u>	<u>6</u>	<u>12</u>	<u>25</u>	<u>50</u>	<u>100</u>	<u>250</u>	<u>400</u>
H_R (Ft.)								
17	85.8	90.7	92.3	96.2	104.2	115.3	132.8	138.2
23	84.4	88.9	90.2	92.0	99.8	114.0	129.0	136.8
28	83.1	87.0	88.6	89.9	98.7	114.1	127.0	135.6
34	82.0	85.7	87.2	88.8	98.1	114.4	125.9	134.3
39	81.0	84.4	86.0	87.7	97.8	113.0	124.0	131.4
45	80.1	83.5	85.3	86.9	97.5	110.6	121.4	128.0
50	79.3	82.6	84.4	86.3	97.1	107.9	118.5	125.9
56	78.5	81.7	83.7	85.6	96.2	106.1	116.2	124.3
61	77.8	81.1	83.4	85.0	95.1	104.4	114.0	121.0
66	77.1	80.4	82.6	84.5	94.1	103.4	112.9	118.9
71	76.4	79.9	82.3	84.0	93.2	102.1	111.3	117.7
76	75.9	79.4	81.8	83.2	92.5	101.6	109.5	115.4
79	75.5	78.5	81.5	82.5	91.7	100.7	108.4	114.3

Table 3.3.1 (continued)
Mean Basic Transmission Loss at One Mile in Area I

Freq. MHz	Horizontal Polarization; $H_T = 80$ Feet									
	H_R (Ft.)	2	6	12	H_R (Ft.)	25	50	100	250	400
17		81.2	86.2	38.5	11	93.4	100.0	102.0	122.1	127.3
23		79.8	84.2	86.4	20	87.6	96.0	101.4	119.9	126.4
28		78.6	82.6	85.1	26	85.9	94.8	102.1	119.0	127.3
34		77.7	81.0	83.6	31	84.4	94.0	101.9	117.0	124.4
39		76.5	80.0	82.5	37	83.3	93.6	100.0	115.0	121.1
45		75.6	79.0	81.6	42	82.8	93.5	98.3	112.7	117.1
50		74.7	78.0	81.0	48	82.2	93.2	95.1	109.5	114.9
56		73.8	77.4	80.6	53	81.8	92.3	93.0	106.2	113.4
61		73.2	76.6	80.0	59	81.3	91.3	91.3	104.6	110.8
66		72.6	75.9	79.5	64	80.6	90.1	90.1	103.1	109.0
71		72.0	75.4	79.1	69	80.1	89.2	89.3	101.9	107.2
76		71.6	75.0	78.6	73	79.6	88.7	88.4	100.8	106.0
79		71.3	74.7	79.0	79	79.1	88.1	87.8	99.7	105.1

Table 3.3.2
Mean Basic Transmission Loss at One Mile in Area I

Vertical Polarization; $H_T = \text{As Shown}$				
H_R (Ft.)	Freq. MHz	Monopole $H_T = 0 \text{ Ft.}$		Dipole $H_T = 20 \text{ Ft.}$
		2	6	12
17	69.3		92.9	106.6
23	69.5		92.9	106.3
28	69.7		92.9	105.6
34	69.7		92.8	104.3
39	69.7		92.8	102.8
45	69.6		92.4	101.5
50	69.7		91.9	100.3
56	69.7		91.4	98.8
61	69.5		91.1	98.2
66	69.5		90.5	97.4
71	69.4		90.1	96.9
76	69.2		89.5	96.0
79	69.5		89.3	95.1
				94.0

Table 3.3.2 (continued)
Mean Basic Transmission Loss at One Mile in Area I

Vertical Polarization; $H_T = \text{As Shown}$

H_R (Ft.)	Freq. MHz	$H_T = 10 \text{ Ft.}$			$H_T = 13 \text{ Ft.}$		
		25	50	100	250	400	
11		118.7	123.3	132.9	142.5	144.2	
20		119.2	118.3	128.6	140.4	142.0	
26		115.2	115.3	126.8	137.6	140.2	
31		113.0	113.2	125.5	135.2	138.3	
37		111.0	111.5	123.3	132.6	136.1	
42		109.4	110.0	120.6	129.8	134.2	
48		108.4	108.3	118.7	129.1	132.2	
53		107.2	107.0	116.4	126.8	130.8	
59		106.1	105.8	114.5	124.9	128.6	
64		104.9	105.0	112.7	122.5	125.9	
69		103.8	103.7	111.4	121.3	125.0	
73		103.0	103.1	110.5	120.1	123.6	
79		102.3	102.3	109.7	119.3	122.3	

Table 3.3.2 (continued)
Mean Basic Transmission Loss at One Mile in Area I

Vertical Polarization; $H_T = 40$ Feet

H_R (Ft.)	Freq. MHz	<u>25</u>	<u>50</u>	<u>100</u>	<u>250</u>	<u>400</u>
11		104.4	112.8	124.2	113.6	138.5
20		103.5	109.8	118.5	129.9	138.5
26		99.2	107.0	116.8	127.2	135.9
31		96.9	104.5	115.0	124.2	135.5
37		95.2	102.7	112.9	122.5	133.0
42		93.6	101.1	110.9	120.5	127.6
48		92.5	99.7	108.5	118.1	125.2
53		91.7	98.6	106.3	115.8	122.7
59		90.8	97.3	104.3	114.1	121.2
64		89.5	96.1	102.9	112.8	119.9
69		88.5	94.8	101.8	111.3	118.7
73		87.7	94.2	100.7	110.5	117.4
79		87.0	93.2	99.7	109.1	116.3

Table 3.3.2 (continued)
Mean Basic Transmission Loss at One Mile in Area I

H_R (Ft.)	Freq. MHz	Vertical Polarization; $H_T = 80$ Feet				
		<u>25</u>	<u>50</u>	<u>100</u>	<u>250</u>	<u>400</u>
11	100.1		107.8	114.4	122.6	131.2
20	99.5		103.0	110.7	121.0	128.3
26	94.6		100.3	108.2	118.5	126.7
31	92.6		97.7	106.7	116.9	123.1
37	90.8		96.0	104.9	113.8	119.7
42	89.2		94.5	102.9	109.8	117.0
48	88.2		92.9	100.1	107.3	113.7
53	87.5		91.4	98.1	104.2	111.1
59	86.8		90.1	96.3	101.8	109.6
64	85.3		89.0	94.3	100.6	108.5
69	84.5		88.0	93.1	99.4	107.2
73	83.8		87.5	92.1	98.2	105.8
79	83.2		86.6	91.6	97.0	104.6

Table 3.3.3
Mean Basic Transmission Loss at One Mile in Area II

H _R (Ft.)		Horizontal Polarization; H _T = As Shown									
		H _T = 13 Ft.					H _T = 40 Ft.				
		25	50	100	250		2	12	50		
	Freq. MHz										
8		110.8	121.0	125.7	132.2		88.9	98.2	114.6		
15		106.5	116.8	122.6	134.6		87.2	93.5	109.1		
23		103.8	115.3	123.2	132.4		85.0	89.8	106.7		
28		102.3	113.7	123.3	132.3		83.1	88.0	105.8		
34		101.1	112.0	122.0	132.1		81.7	86.6	104.7		
40		100.4	111.1	122.3	127.7		80.8	85.4	103.5		
45		99.8	110.3	122.2	129.2		80.0	84.4	103.4		
50		99.4	110.1	122.0	129.2		79.0	83.4	103.5		
55		98.9	109.4	120.4	130.7		78.2	82.8	103.3		
60		98.1	109.1	119.9	131.3		77.6	82.2	102.7		
65		97.5	108.7	120.0	129.7		77.1	81.6	102.4		
70		97.2	107.9	119.2	128.3		76.6	81.1	102.0		
75		96.8	107.0	119.1	126.0		76.0	80.6	101.1		
80		96.4	106.2	117.0	126.0		75.4	80.1	100.5		
85		96.0	105.2	115.7	124.1		74.8	80.0	99.8		
90		95.4	104.0	114.7	124.9		74.1	79.6	98.7		
95		95.0	103.4	113.1	124.6		73.8	79.2	98.9		
100		94.4	102.5	111.7	123.0		73.4	79.0	97.0		
105		94.0	102.0	110.7	121.9		73.3	78.5	96.2		
110		93.5	101.8	109.7	121.2		73.3	78.2	95.7		
115		93.1	101.2	108.6	119.5		72.9	77.9	95.2		

Table 3.5.3 (continued)
Mean Basic Transmission Loss at One Mile in Area II

H _R (Ft.)		Horizontal Polarization; H _T = As Shown											
		H _T = 80 Ft.						H _T = 120 Ft.					
		Freq. MHz	2	12	25	50	100	25	50	100	250		
8			86.8	93.5	99.0	112.4	121.9	96.0	105.1	112.5	119.6		
15			85.3	88.2	95.6	108.1	118.2	92.2	100.7	110.0	119.2		
23			82.6	84.8	93.0	104.6	120.7	89.1	98.8	111.4	121.7		
28			81.0	82.9	91.4	103.7	120.6	87.5	98.3	112.0	121.5		
34			79.8	81.6	90.4	102.8	120.1	86.4	97.0	109.4	121.1		
40			78.5	80.4	89.7	102.5	118.7	85.8	96.2	108.4	121.0		
45			77.7	79.4	89.0	102.1	117.4	85.4	96.2	107.7	120.5		
50			76.7	78.7	88.7	101.4	115.7	85.3	96.2	106.7	119.6		
55			75.9	78.0	87.8	101.1	115.6	85.2	97.2	106.2	117.7		
60			75.1	77.4	87.1	100.5	115.1	84.7	96.5	105.3	116.2		
65			74.5	76.8	86.4	100.3	114.5	84.0	95.5	104.4	113.4		
70			74.1	76.3	86.2	100.2	114.1	83.7	94.8	102.5	112.8		
75			73.4	76.0	86.0	100.2	112.6	83.5	94.5	101.3	110.5		
80			73.0	75.5	85.8	100.1	111.5	83.2	93.8	100.5	108.6		
85			72.1	75.1	85.4	99.0	110.1	83.1	93.0	99.4	107.0		
90			72.0	74.8	85.0	97.5	108.5	83.1	92.2	98.8	106.5		
95			71.5	74.5	84.4	96.3	107.6	82.8	91.4	97.7	105.4		
100			71.2	74.3	84.0	95.5	106.7	82.8	90.4	96.5	103.8		
105			70.6	74.0	83.6	94.7	105.8	82.2	89.5	95.5	103.0		
110			70.5	73.9	83.2	94.3	105.0	81.8	88.7	94.3	101.6		
115			69.9	73.6	82.7	94.0	104.0	80.9	87.8	93.3	100.4		

Table 3.3.4
Mean Basic Transmission Loss at One Mile in Area II

		Vertical Polarization; $H_T = \text{As Shown}$									
		$H_T = 0 \text{ Ft.}$					$H_T = 13 \text{ Ft.}$				
		Freq. MHz	2	12	25	50	25	50	100	250	
H_R (Ft.)											
8		74.9	117.1	132.8	139.5		131.5	138.5	143.5	142.7	
15		74.9	117.5	130.3	135.0		129.9	134.4	138.6	141.6	
23		75.1	117.8	128.0	135.2		127.6	131.8	136.9	141.2	
28		75.4	117.4	126.2	133.5		125.6	129.7	135.2	141.5	
34		75.7	116.5	125.0	131.9		123.8	128.7	133.3	140.4	
40		75.7	114.8	123.5	131.0		122.1	128.1	130.6	141.2	
45		75.8	113.1	122.1	130.0		120.5	127.4	129.0	141.1	
50		76.0	111.5	121.2	128.5		119.6	126.3	129.4	140.6	
55		76.3	110.2	120.3	127.8		118.3	125.4	128.9	139.6	
60		76.4	109.2	119.6	127.1		118.0	124.4	127.9	138.8	
65		76.7	108.1	119.0	126.1		117.2	123.0	127.0	137.3	
70		76.5	106.7	118.0	125.7		116.9	122.0	125.9	135.8	
75		76.6	105.8	117.1	125.2		116.0	121.5	124.1	135.3	
80		76.5	105.1	115.5	124.2		114.9	120.5	123.1	132.5	
85		76.7	104.2	114.6	122.7		113.9	119.2	121.4	132.6	
90		76.8	103.4	113.8	121.2		112.9	118.6	120.6	132.4	
95		76.8	103.0	113.2	120.4		112.4	117.7	119.5	129.4	
100		75.8	102.4	112.4	119.3		111.5	116.7	119.0	126.7	
105		76.8	102.0	111.7	117.3		111.0	116.1	117.8	126.5	
110		76.7	101.4	110.9	116.7		110.3	115.3	117.2	124.9	
115		76.5	100.8	110.1	115.8		109.6	114.2	115.7	123.0	

Table 3.3.4 (continued)
Mean Basic Transmission Loss at One Mile in Area II
Vertical Polarization; $H_T = \text{As Shown}$

H_R (Ft.)	Freq. MHz	$H_T = 40$ Ft.			$H_T = 80$ Ft.			$H_T = 120$ Ft.		
		50	25	50	100	25	50	100	250	
8		133.1	115.0	124.7	130.1	107.4	115.4	119.8	128.3	
15		129.8	111.1	120.5	128.9	105.2	111.5	119.4	126.3	
23		124.1	109.7	117.2	128.6	103.0	109.0	117.4	127.3	
28		123.1	108.1	115.8	128.5	101.0	107.7	115.8	126.4	
34		122.8	105.4	113.8	126.8	99.1	106.4	114.7	126.9	
40		121.8	104.7	112.0	124.4	97.2	105.0	115.0	122.8	
45		120.4	103.6	110.8	123.0	95.8	103.4	112.4	122.0	
50		119.0	102.7	110.0	122.1	94.7	102.1	110.4	123.2	
55		117.6	101.6	109.2	119.5	94.1	101.0	109.2	121.9	
60		116.8	100.2	108.2	117.3	93.2	99.8	107.4	119.7	
65		115.4	98.7	107.1	116.7	91.9	98.2	106.5	119.1	
70		114.7	97.4	106.2	116.0	91.0	97.2	105.4	116.7	
75		113.8	96.4	104.7	113.8	90.0	96.4	103.4	113.8	
80		113.2	95.6	103.4	112.0	88.8	95.5	101.8	113.0	
85		112.7	94.7	102.2	110.5	88.0	94.1	100.4	112.2	
90		112.0	93.8	101.4	110.2	87.4	93.0	99.3	110.5	
95		111.5	93.1	100.6	110.4	86.5	91.8	98.1	108.1	
100		110.1	92.4	99.5	109.2	85.8	91.2	96.8	106.1	
105		109.2	91.7	98.5	108.2	85.2	90.3	95.6	105.7	
110		108.2	91.1	97.5	106.8	84.7	89.2	94.2	104.3	
115		107.2	90.5	96.7	105.5	84.1	88.7	93.1	103.0	

Table 3.3.5
Standard Deviation of Basic Path Loss at One Mile in Area I

H_R (Ft.)	Horizontal Polarization; $l_T = 13$ Feet					
	Freq. MHz	<u>25</u>	<u>50</u>	<u>100</u>	<u>250</u>	<u>400</u>
11		4.7	6.0	6.4	6.5	9.5
20		3.9	4.4	5.7	6.9	8.8
26		3.7	4.3	6.7	6.8	7.8
31		3.8	4.0	6.6	6.0	7.3
37		3.8	3.9	6.7	6.0	6.3
42		3.6	3.8	6.2	6.6	7.8
48		3.4	4.0	5.7	6.1	8.7
53		3.5	4.2	5.3	5.4	8.0
59		3.4	4.1	5.0	5.3	8.4
64		3.2	4.3	5.2	5.7	7.9
69		3.1	4.2	4.8	6.0	6.8
73		3.1	4.2	4.7	5.7	7.7
79		3.1	4.3	4.7	5.3	7.4

Table 3.3.5 (continued)
Standard Deviation of Basic Path loss at One Mile in Area 1

Freq. MHz	Horizontal Polarization; H _T = 40 Feet								
	2	6	12	H _R (Ft.)	25	50	100	250	400
17	2.1	2.9	2.5	11	3.9	3.7	7.3	9.1	8.8
23	2.0	2.9	2.5	20	3.9	3.5	6.2	9.1	7.8
28	1.9	3.0	2.2	26	3.7	3.3	6.1	8.6	7.7
34	1.8	2.9	2.4	31	4.1	3.3	6.5	8.9	8.2
39	1.6	3.0	2.3	37	4.1	3.1	6.8	9.4	9.1
45	1.7	2.7	2.4	42	3.9	3.0	6.8	10.2	9.8
50	1.5	2.6	2.4	48	3.6	3.0	7.0	9.5	10.1
56	1.5	2.5	2.4	53	3.7	3.2	6.8	10.1	10.5
61	1.4	2.6	2.3	59	3.1	3.5	6.9	8.9	10.3
66	1.4	2.5	2.5	64	3.2	3.4	7.1	9.0	9.6
71	1.4	2.4	2.5	69	3.1	3.2	7.0	8.4	8.7
76	1.4	2.4	2.6	73	2.9	3.5	7.4	7.3	8.3
79	1.5	1.8	2.4	79	2.9	3.6	7.7	7.0	8.0

Table 3.3.5 (continued)
Standard Deviation of Basic Path Loss at One Mile in Area I

Freq. MHz	Horizontal Polarization; H _T - 80 Feet								
	<u>2</u>	<u>6</u>	<u>12</u>	<u>H_R (Ft.)</u>	<u>25</u>	<u>50</u>	<u>100</u>	<u>250</u>	<u>400</u>
17	1.6	2.3	2.6	11	4.3	4.0	4.5	8.4	9.1
23	1.5	2.2	2.5	20	3.3	4.2	3.9	8.2	7.1
28	1.5	2.3	2.2	26	3.4	4.0	4.4	8.3	7.9
34	1.4	2.2	2.3	31	3.4	3.6	4.5	8.0	8.5
39	1.4	2.2	2.4	37	3.2	3.5	5.0	9.5	9.1
45	1.2	2.3	2.6	42	3.1	3.3	5.3	10.7	8.4
50	1.3	2.2	2.7	48	3.2	3.7	4.8	9.8	8.6
56	1.3	2.3	2.9	53	3.0	3.8	4.2	9.0	8.2
61	1.3	2.3	3.2	59	3.2	4.0	4.2	9.3	9.1
66	1.2	2.5	3.4	64	2.9	3.8	4.0	9.2	9.0
71	1.4	2.7	3.7	69	2.8	3.8	4.0	8.6	8.9
76	1.3	2.9	3.8	73	3.0	4.1	4.2	8.6	8.8
79	1.2	3.0	4.1	79	3.1	4.1	4.4	8.0	9.2

Table 3.3.6
Standard Deviation of Basic Path Loss at One Mile in Area I

Vertical Polarization; $H_T = \text{As Shown}$					
H_R (Ft.)	Freq. MHz	Monopole $H_T = 0$ Ft.		Dipole $H_T = 20$ Ft.	
		2	6	12	12
17	2.3		3.2	2.3	3.5
23	2.2		3.2	2.1	3.5
28	2.4		3.3	2.0	3.2
34	2.4		3.5	1.7	3.2
39	2.4		3.6	1.8	3.1
45	2.4		3.7	1.7	3.2
50	2.3		3.6	1.7	3.1
56	2.3		3.3	1.8	3.4
61	2.7		3.2	1.9	3.3
66	2.6		3.0	1.8	3.1
71	2.6		3.2	1.9	3.3
76	2.8		3.0	1.7	3.4
79	3.0		3.6	1.9	3.8

Table 3.3,6 (continued)
Standard Deviation of Basic Path Loss at One Mile in Area I

Vertical Polarization; H_T = As Shown						
H_R (Ft.)	Freq. MHz	$H_T = 10$ Ft.		$H_T = 13$ Ft.		
		25	50	100	250	400
11	5.2		6.5	6.7	5.8	7.3
20	5.7		6.5	6.9	6.1	9.9
26	5.5		5.7	6.9	6.6	8.4
31	5.3		5.0	6.6	7.0	7.7
37	5.0		5.1	6.0	6.0	8.7
42	4.8		5.3	5.4	6.9	9.7
48	4.9		5.1	5.6	8.0	8.3
53	4.9		5.4	5.5	8.5	8.8
59	4.8		5.4	5.3	8.7	8.1
64	4.8		5.4	5.1	8.1	6.9
69	4.8		5.4	4.8	7.5	7.0
73	4.6		5.2	4.7	7.3	7.4
79	4.2		5.3	4.7	7.0	6.5

Table 3.3.6 (continued)
Standard Deviation of Basic Path Loss at One Mile in Area I

H_R (Ft.)	Freq. MHz	Vertical Polarization; $H_T = 40$ Feet				
		<u>25</u>	<u>50</u>	<u>100</u>	<u>250</u>	<u>400</u>
11	4.5		7.5	7.4	9.1	8.8
20	3.1		7.2	7.6	8.6	7.9
26	3.2		6.3	7.9	6.3	7.4
31	3.1		5.2	8.3	6.5	7.6
37	3.3		4.7	8.4	8.0	8.7
42	3.3		4.8	8.0	7.3	8.3
48	3.3		4.8	7.1	7.2	8.6
53	3.3		4.9	6.3	7.5	9.0
59	3.4		4.9	6.2	7.4	9.3
64	3.2		4.8	6.0	7.3	9.3
69	3.1		4.8	5.7	7.2	8.3
73	3.2		5.0	5.7	7.1	8.2
79	3.2		5.0	5.3	7.1	7.5

Table 3.3.6 (continued)
Standard Deviation of Basic Path Loss at One Mile in Area I

<u>H_R (Ft.)</u>	Vertical Polarization; H _T = 80 Feet					
	<u>Freq. MHz</u>	<u>25</u>	<u>50</u>	<u>100</u>	<u>250</u>	<u>400</u>
11		4.5	6.9	7.0	9.5	10.1
20		4.7	6.1	8.6	10.1	9.4
26		3.7	5.2	8.2	10.0	9.3
31		3.3	4.2	8.1	9.3	8.2
37		3.7	3.7	8.2	9.6	8.3
42		3.6	3.8	7.4	10.9	7.9
48		3.7	3.7	6.7	9.7	9.0
53		3.5	3.9	6.1	9.8	9.4
59		3.7	3.8	5.6	9.0	11.1
64		3.6	3.8	4.9	8.4	10.3
69		3.7	3.8	4.8	8.2	9.7
73		3.8	4.2	4.8	8.2	9.8
79		3.9	3.9	5.0	8.2	9.8

Table 3.3.7
Standard Deviation of Basic Path Loss at One Mile in Area II
Horizontal Polarization; $H_T = \text{As Shown}$

H_R (Ft.)	Freq. MHz	$H_T = 13 \text{ Ft.}$				$H_T = 40 \text{ Ft.}$			
		50		100	250	2		12	50
		25							
8	6.8	7.2	8.0	12.3	4.0	4.9	6.6		
15	5.6	6.7	9.1	13.7	6.4	4.4	4.1		
23	5.6	6.6	10.7	13.5	5.9	4.6	5.0		
28	5.7	7.3	10.7	12.4	5.7	4.4	6.7		
34	5.6	6.3	9.9	12.7	5.9	4.1	6.7		
40	5.7	5.8	10.0	10.5	5.9	4.0	5.8		
45	5.6	5.8	10.5	8.7	6.0	4.0	5.6		
50	5.9	5.8	10.4	11.0	6.1	3.8	5.5		
55	6.2	5.5	8.5	12.8	6.2	3.4	5.6		
60	5.9	5.3	8.1	12.2	6.0	3.3	4.9		
65	6.1	5.4	7.7	11.0	6.2	3.3	5.0		
70	6.1	5.3	6.5	9.7	6.3	3.4	5.5		
75	5.9	5.4	7.1	8.4	6.0	3.3	4.9		
80	5.7	5.5	5.9	6.9	6.1	3.1	4.8		
85	5.7	5.6	5.3	7.4	5.9	3.1	4.8		
90	5.5	5.5	5.3	9.0	6.1	3.0	4.6		
95	5.2	6.0	5.3	9.2	6.0	3.0	4.4		
100	4.9	5.9	5.1	9.5	6.0	2.9	3.9		
105	4.6	5.6	5.2	8.8	5.5	2.9	3.6		
110	4.5	5.3	5.5	9.4	5.3	2.8	3.3		
115	4.3	5.0	5.3	8.7	5.2	2.7	3.4		

Table 3.3.7 (continued)
Standard Deviation of Basic Path Loss at One Mile in Area II

		Horizontal Polarization; $H_T = \text{As Shown}$									
		$H_T = 80 \text{ Ft.}$					$H_T = 120 \text{ Ft.}$				
$H_R (\text{Ft.})$	Freq. MHz	2	12	25	50	100	25	50	100	250	
8		6.9	3.7	4.2	7.9	8.9	3.4	6.2	6.8	8.2	
15		6.7	3.1	4.2	6.6	7	3.6	4.7	5.7	6.4	
23		6.8	3.6	4.9	7.0	8.3	3.8	5.1	6.2	7.8	
28		6.9	3.7	4.9	7.3	10.3	3.8	6.2	6.5	7.3	
34		6.9	3.4	4.5	6.1	10.1	3.6	4.8	5.5	7.1	
40		7.1	3.3	4.4	5.9	6.7	3.8	3.8	5.4	7.2	
45		6.8	3.4	4.0	5.5	6.1	4.4	3.6	5.4	7.1	
50		6.6	3.4	3.7	4.5	5.8	4.9	3.6	5.5	6.5	
55		6.4	3.2	3.4	4.6	5.5	5.4	5.1	5.0	5.2	
60		6.4	3.3	3.1	4.3	4.9	4.9	4.2	4.6	5.2	
65		6.3	3.1	3.5	3.8	5.3	4.0	3.8	4.7	5.3	
70		6.3	3.2	4.0	3.4	5.7	3.6	4.0	4.9	5.6	
75		6.2	3.2	4.4	3.3	5.4	3.6	4.8	4.8	5.7	
80		6.3	3.2	4.4	4.6	5.6	3.8	4.9	5.0	4.8	
85		5.5	3.3	4.2	4.6	5.6	4.3	4.2	4.6	4.0	
90		5.9	3.4	3.7	3.5	5.6	4.9	4.3	5.0	4.7	
95		5.9	3.4	3.4	3.6	5.1	5.0	4.2	5.4	5.1	
100		5.9	3.5	3.3	3.8	5.2	5.1	4.6	5.1	5.0	
105		5.8	3.6	3.3	3.8	5.4	5.0	4.6	5.1	5.3	
110		5.8	3.8	3.3	4.1	5.4	4.8	4.4	5.0	5.4	
115		5.7	4.0	3.4	4.4	5.4	4.5	4.2	5.2	5.8	

Table 3.3.8
Standard Deviation of Basic Path Loss at One Mile in Area II
Vertical Polarization; $H_T = \text{As Shown}$

H_R (Ft.)	Freq. MHz	$H_T = 0$ Ft.				$H_T = 13$ Ft.			
		2	12	25	50	25	50	100	250
8		4.1	7.8	6.7	5.4	8.4	9.1	11.1	9.8
15		4.0	6.9	7.0	5.8	7.8	6.9	7.1	11.1
23		3.9	6.7	7.6	8.3	7.4	5.8	7.9	10.3
28		3.9	6.6	8.0	8.5	7.1	5.1	8.2	11.1
34		3.9	6.4	8.5	9.4	6.7	5.5	8.4	10.7
40		3.8	6.5	8.2	9.5	6.6	6.2	9.6	7.9
45		3.9	6.4	8.6	9.0	6.8	6.5	9.6	8.8
50		3.9	6.7	9.0	8.8	6.6	6.4	10.0	8.5
55		3.9	6.3	9.1	9.8	6.9	6.1	8.4	5.3
60		3.9	6.3	10.4	10.1	6.9	6.7	8.2	6.7
65		4.0	6.5	8.8	9.5	6.7	6.9	8.5	6.2
70		4.0	6.7	8.1	8.1	6.6	7.1	7.7	8.3
75		4.0	6.5	7.4	8.0	6.8	7.7	6.9	10.0
80		4.1	6.4	6.7	8.3	6.8	7.3	7.1	10.1
85		4.0	6.3	6.6	8.2	6.9	6.8	6.3	9.3
90		4.0	6.5	6.6	8.1	6.3	6.6	7.2	9.2
95		4.0	6.5	6.5	8.3	5.9	6.4	7.4	9.2
100		4.1	6.2	6.6	8.4	5.5	5.7	8.0	9.2
105		4.2	6.1	6.7	8.1	5.5	5.2	6.9	9.9
110		4.3	6.1	6.7	7.6	5.4	4.7	7.3	8.9
115		4.4	6.0	6.7	7.2	5.6	4.5	6.3	8.1

Table 3.3.8 (continued)
Standard Deviation of Basic Path Loss at One Mile in Area VI
Vertical Polarization; H_T = As Shown

H_R (Ft.)	Freq. MHz	$H_T = 40$ Ft.			$H_T = 80$ Ft.			$H_T = 120$ Ft.		
		50	25	50	25	50	25	25	50	250
8										
15		6.4	6.2	7.8	7.9	6.8	4.4	7.3	5.5	
23		7.8	5.3	9.1	8.7	7.2	4.0	6.6	7.3	
28		8.1	5.2	7.1	6.6	7.6	4.4	5.2	6.0	
34		8.4	5.9	6.7	8.0	7.3	4.2	5.2	4.9	
40		9.5	6.0	3.5	8.6	6.8	4.2	4.9	5.1	
45		10.7	5.4	5.1	7.2	6.0	4.2	7.7	6.1	
50		9.7	5.0	5.5	6.9	4.4	4.0	6.1	5.3	
55		8.1	4.7	6.1	6.3	4.4	3.7	5.5	5.9	
60		7.9	4.2	5.7	5.8	4.0	3.7	5.7	6.7	
65		7.4	3.9	5.7	5.7	3.7	3.8	4.2	6.4	
70		7.2	3.5	5.4	6.5	3.8	3.8	4.2	7.4	
75		7.0	3.2	4.7	7.3	3.6	3.7	5.2	8.5	
80		6.8	2.9	4.3	5.6	3.9	3.5	5.2	8.4	
85		7.1	2.8	4.1	5.5	4.4	3.1	4.6	6.7	
90		7.6	2.7	4.0	5.3	4.7	3.1	5.0	6.7	
95		8.3	2.6	4.4	6.4	4.6	3.1	4.7	7.0	
100		8.4	2.7	4.3	7.5	4.2	3.2	4.0	7.2	
105		8.0	2.7	4.2	7.7	4.4	3.3	4.2	7.3	
110		8.3	2.8	4.2	7.7	4.5	3.4	4.5	6.6	
115		7.7	3.0	4.1	6.7	4.6	3.7	4.4	5.6	
		7.3	2.8	4.2	7.3	4.8	3.8	4.6	6.1	

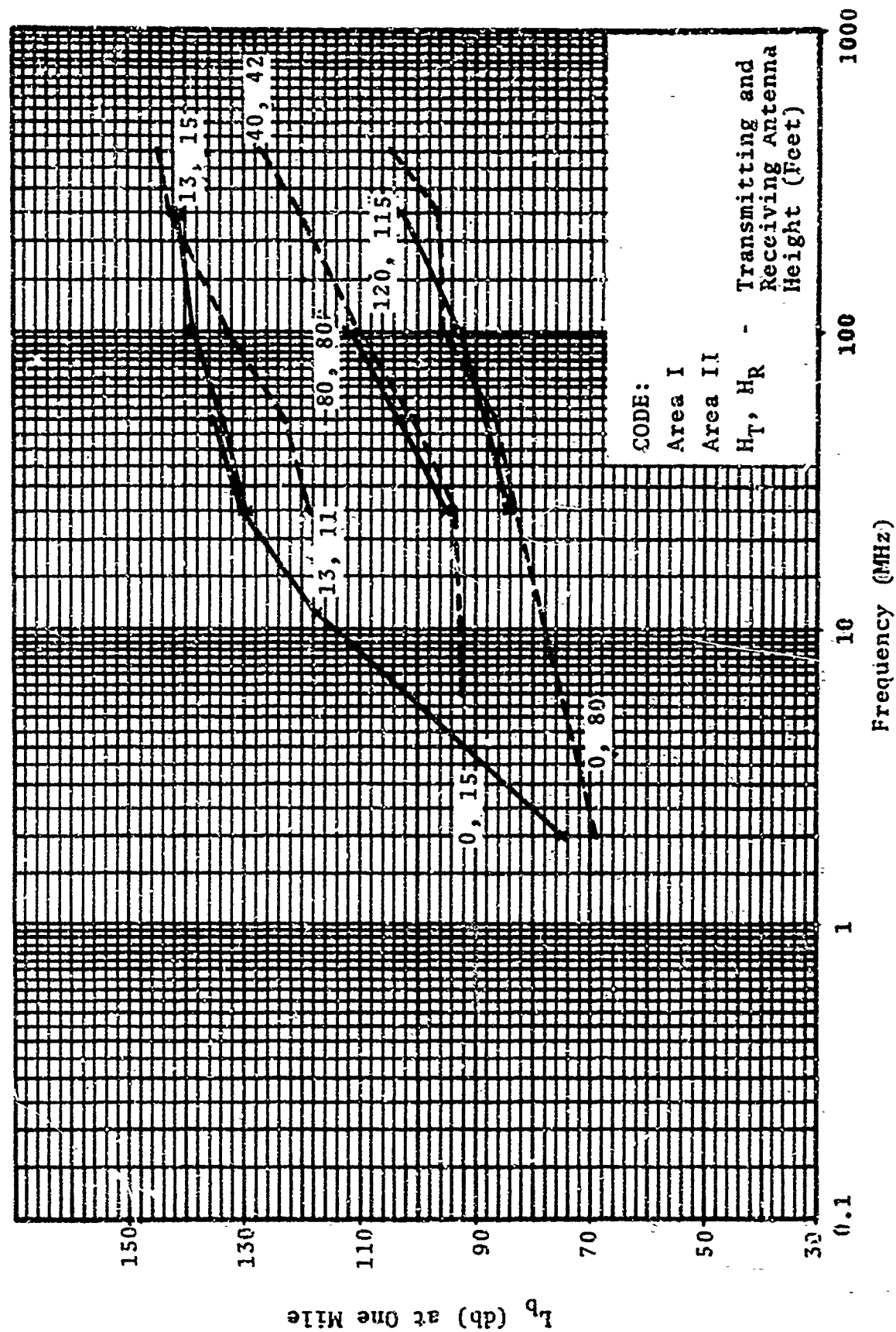


Figure 3.3.1 Mean Basic Transmission Loss at One Mile, V Polarization

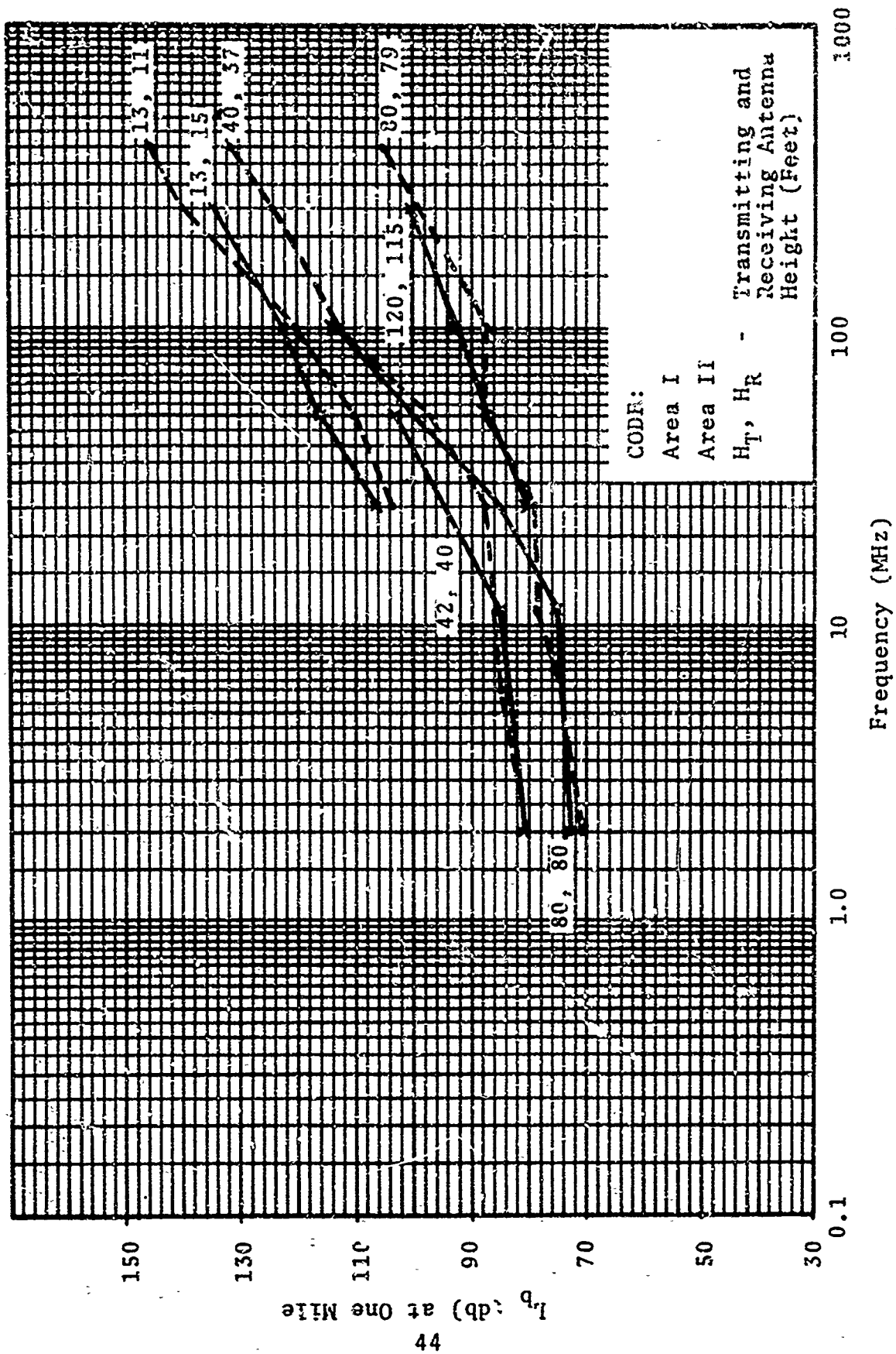


Figure 3.3.2 Mean Basic Transmission Loss at One Mile, H Polarization

polarization. Figures 3.3.1 and 3.3.2 show that the transmission loss for both environments decreases with increasing antenna height (height-gain) and generally increases with increasing frequency.

Also, the height-gain may be seen to be a function of height and frequency -- generally being greater at the lower heights at lower frequencies. Figures 3.3.1 and 3.3.2 show that the losses at antenna heights of 120 - 115 feet and 80 - 80 feet in Area II are about the same as those at antenna heights of 80 - 79 feet and 40 - 42 feet, respectively, in Area I, for the same polarizations, and at the frequencies greater than ≈ 25 MHz. This is in keeping with the fact that, according to the lateral wave theory, it is the foliage above the antennas which constitutes the major propagation path, and hence losses, within the foliage.

These data also show that the losses are about the same in the two areas for equal antenna heights at frequencies less than ≈ 12 MHz and for all frequencies compared here for the lower antennas. The causes of these results are not as easily visualized as the previous case, but the results may also be seen to be in qualitative agreement with the lateral wave concepts because the attenuation rate of the signal through the foliage is a function of frequency and, for reasonable effective electrical parameters for the forest, undergoes a significant increase at around 12 - 25 MHz [Tamir, 1967]. It may also be seen that the loss is different for horizontal and vertical polarizations. This is discussed later, and attention is now turned to a quantitative comparison of theoretical results with experimental data.

The theoretical transmission loss is obtained from Eqs. 3.1.1 and 3.1.2 and is plotted for Area I, along with

the experimental results, in Figures 3.3.3 and 3.3.4. Figures 3.3.5 and 3.3.6 are similar results for Area II. A number of different dielectric constants, ϵ , and conductivity, σ , for the ground and foliage medium (slab), and slab heights, h , were assumed in obtaining the theoretical values. The constants of air are assumed to be those of a vacuum. For the ground, the constants ranged from

$$10 \leq \epsilon_g \leq 25$$

and

$$1.0 \text{ mmhos/m} \leq \sigma_g \leq 25 \text{ mmhos/m.}$$

For the jungle,

$$1.01 \leq \epsilon_j \leq 1.5,$$

$$0.01 \text{ mmhos/m} \leq \sigma_j \leq 1.0 \text{ mmhos/m,}$$

and

$$40 \text{ ft.} \leq h \leq 70 \text{ ft. for Area I,}$$

$$60 \text{ ft.} \leq h \leq 110 \text{ ft. for Area II.}$$

Obviously not all possible combinations of these were employed. The jungle height was changed in 10-foot increments and, once the values of ϵ_j and σ_j were narrowed to a range giving a reasonable fit to the data, the ϵ_j was changed in increments of 0.01 and σ_j in increments of 0.01 mmhos/m with the ϵ_g and σ_g held constant. The latter, ϵ_g and σ_g , only weakly influence the loss, but the effect of changing ϵ_j , σ_j and h_j is generally pronounced.

The theoretical transmission loss values shown, which represent the best over-all fit obtained to the data, were obtained with

$$\sigma_g = 10 \text{ mmhos/m,}$$

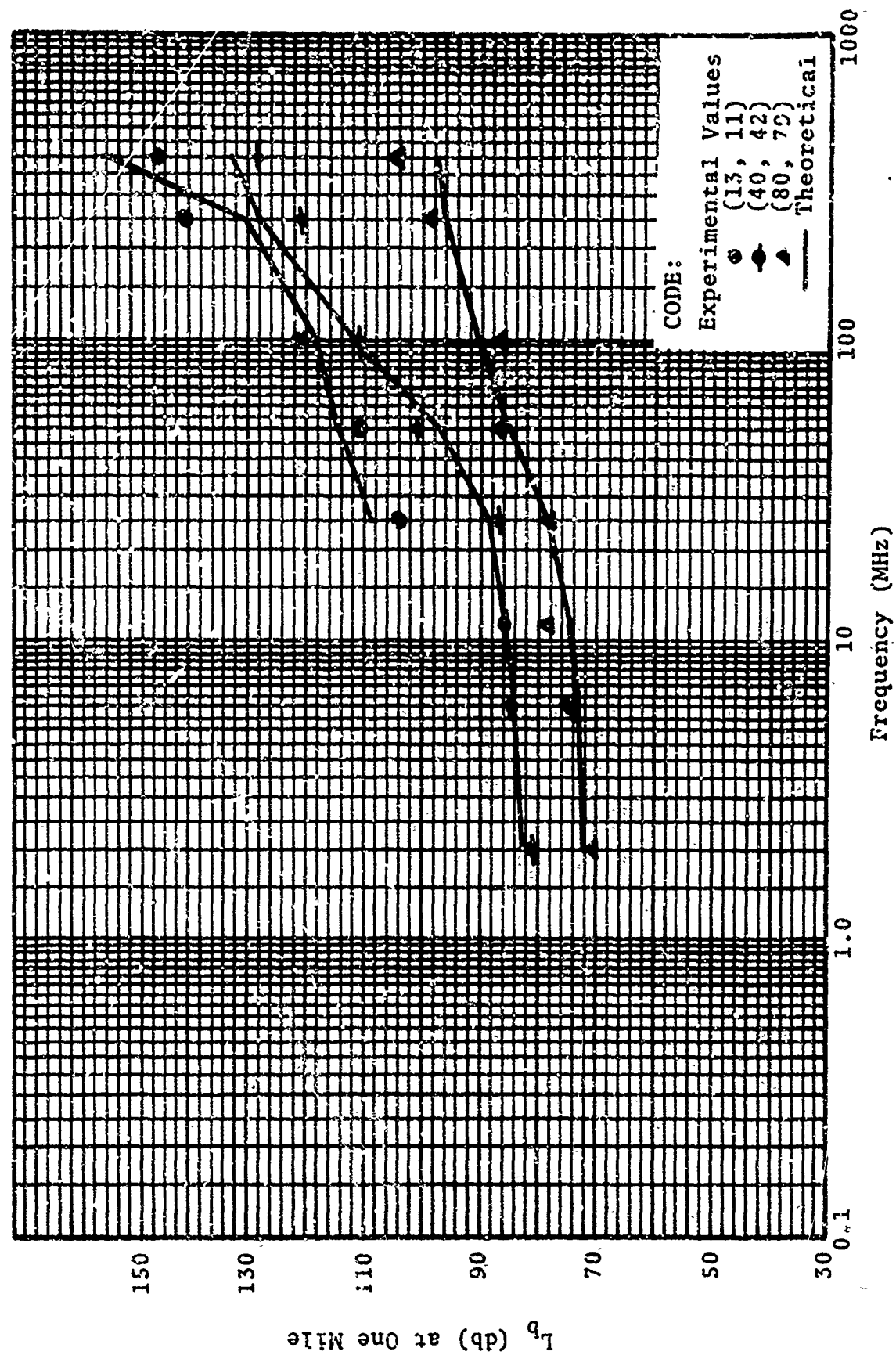


Figure 3.3.3 Mean Basic Transmission Loss at One Mile, H Polarization, Area I

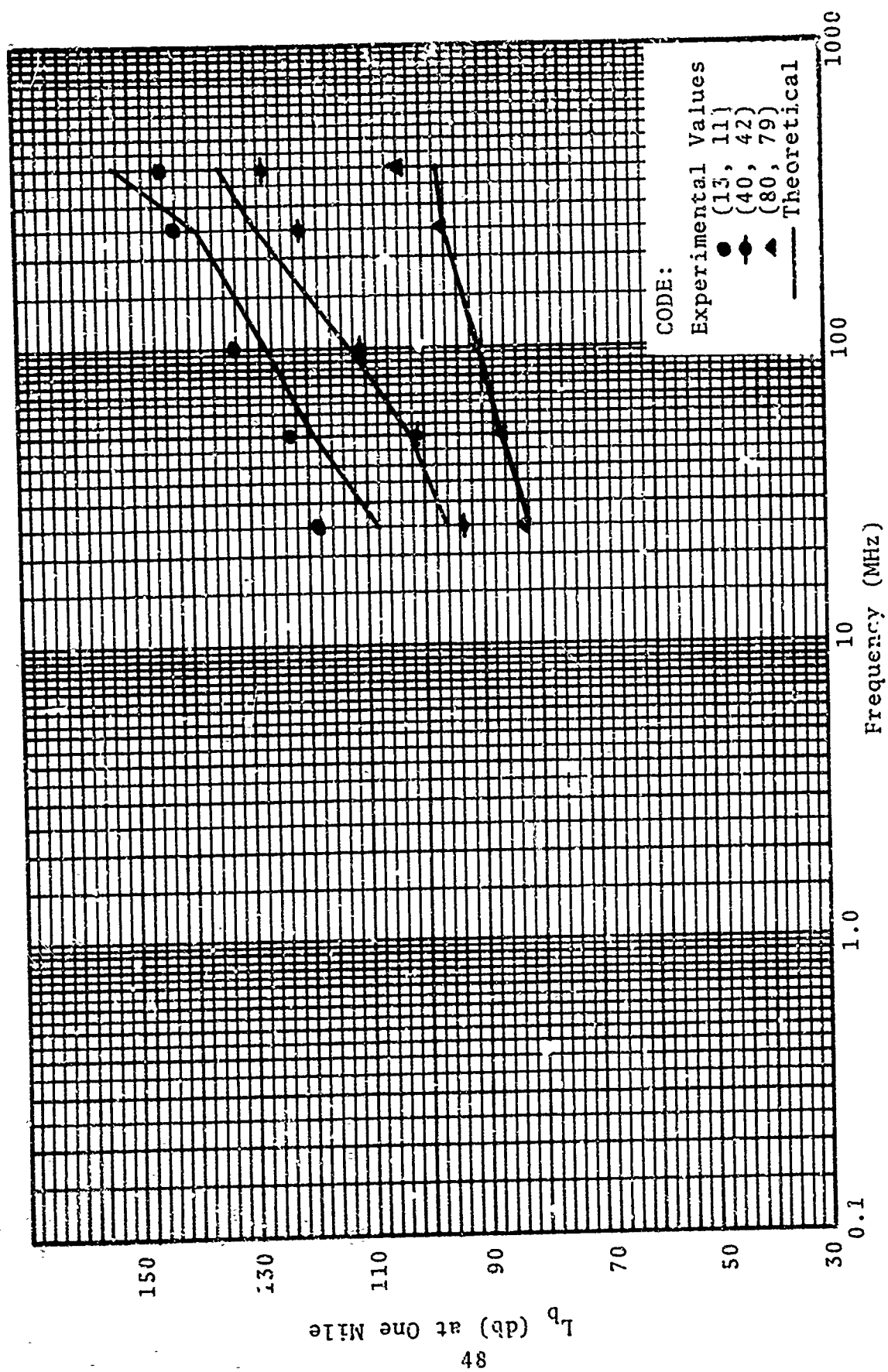


Figure 3.3.4 Mean Basic Transmission Loss at One Mile, V Polarization, Area I

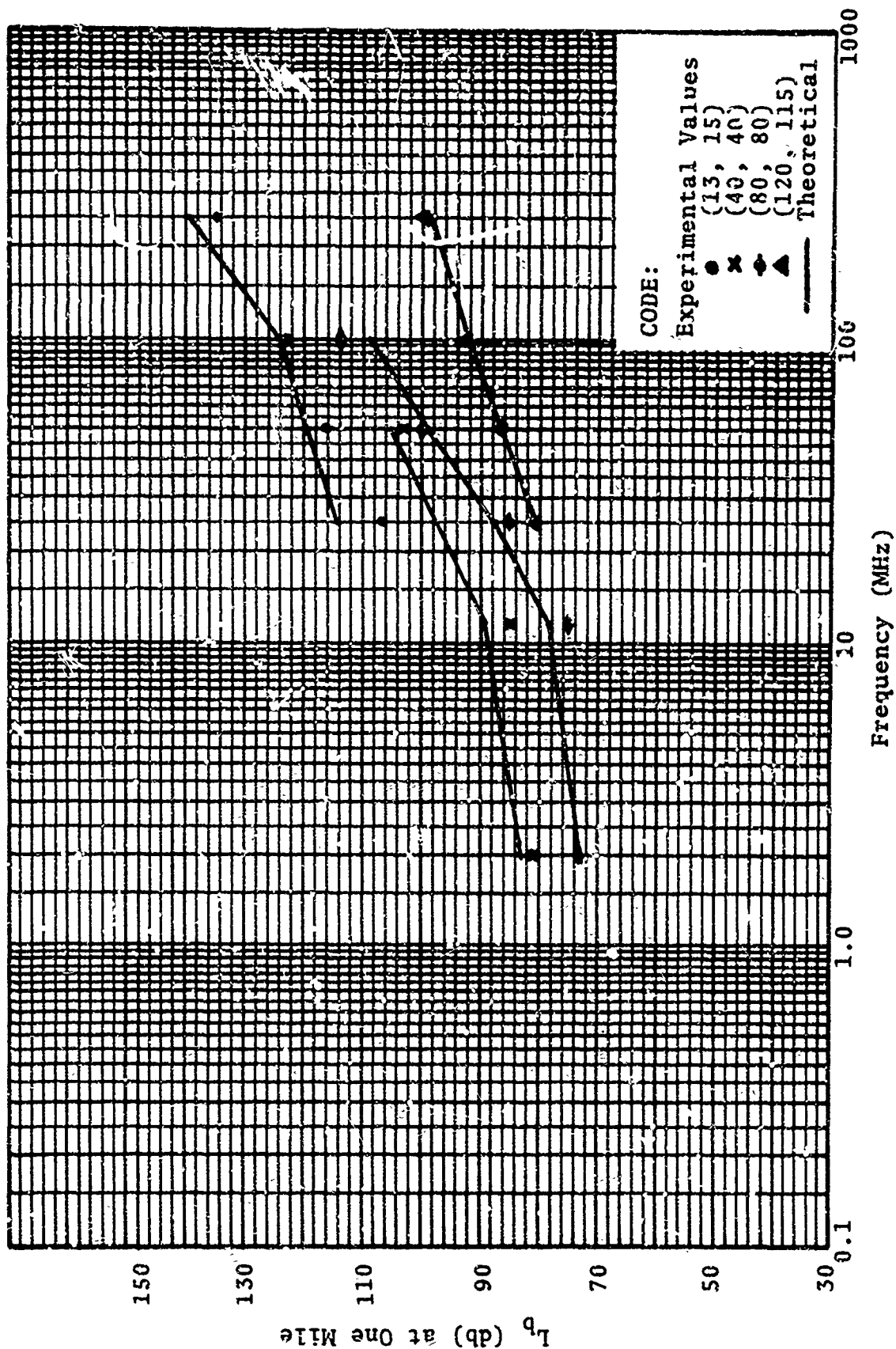


Figure 3.3.5 Mean Basic Transmission Loss at One Mile, H Polarization, Area II

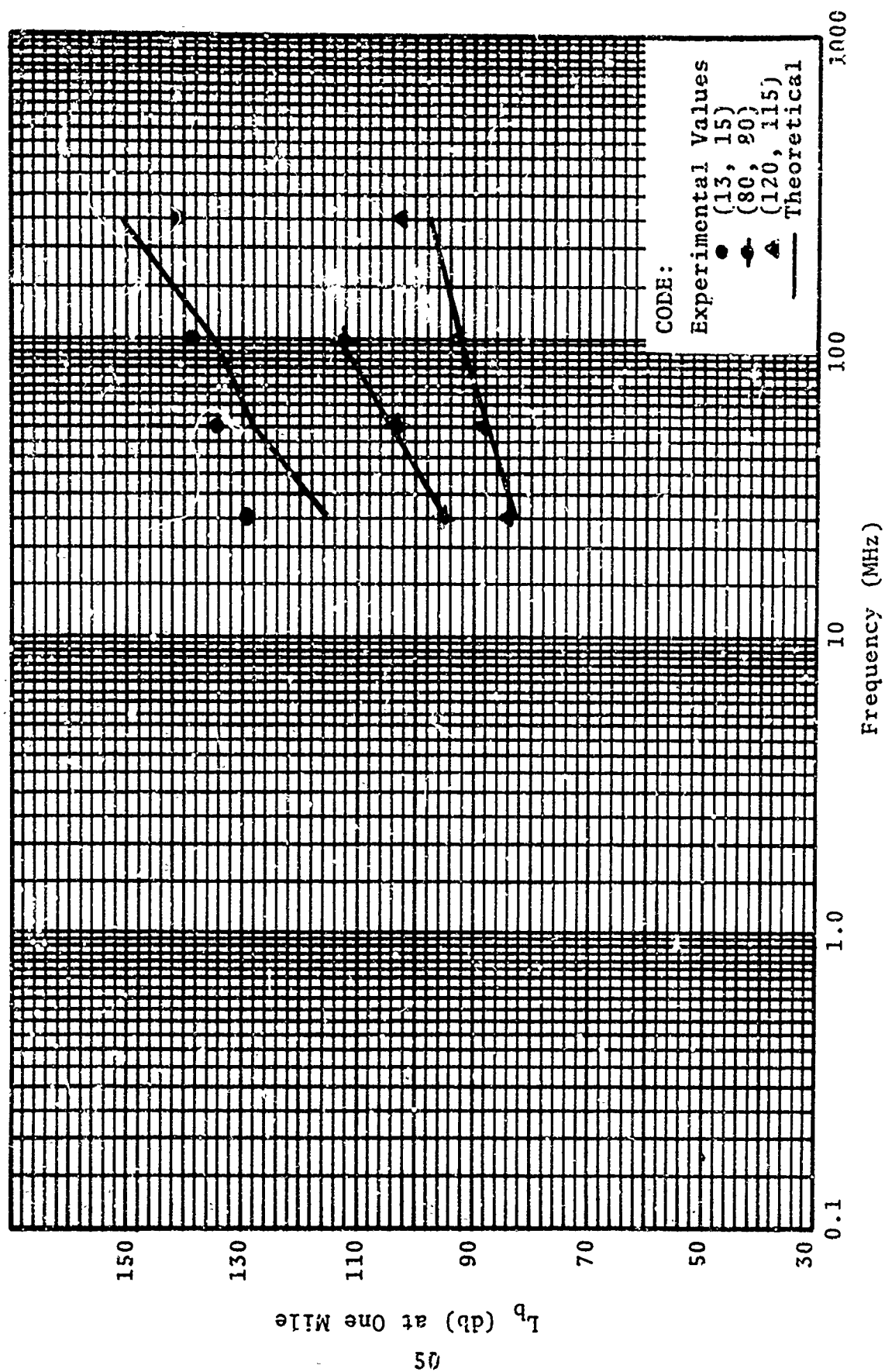


Figure 3.3.6 Mean Basic Transmission Loss at One Mile, V Polarization, Area II

$$\epsilon_g = 15,$$

$$\epsilon_j = 1.01$$

for both polarizations and both areas.

For Area I,

$$\sigma_j = 0.04 \text{ mmhos/m}$$

for horizontal polarization, and

$$\sigma_j = 0.05 \text{ mmhos/m}$$

for vertical polarization.

For Area II,

$$\sigma_j = 0.03 \text{ mmhos/m}$$

for horizontal polarization, and

$$\sigma_j = 0.04 \text{ mmhos/m}$$

for vertical polarization.

The best fit effective slab height was

$$h = 60 \text{ feet for Area I}$$

$$h = 100 \text{ feet for Area II.}$$

The resultant theoretical loss is, with few exceptions, within 1σ of the mean of the experimental data. Better agreement could be obtained, with different values, if the frequency range of interest is narrowed, or if the electrical constants and/or effective height are assumed to be functions of frequency. Such refinement complicates the model and, because of the fairly large spatial variations of signal strength typically encountered [Jansky & Bailey, 1966], does not seem warranted and the agreement between theory and experiment is deemed satisfactory. Also, a few theoretical

checks were made with fixed transmitter antenna height and variable receive antenna heights. In these cases, the differences between theory and experiment were bounded by the differences obtained above with equal antenna heights, as might have been anticipated, since the extremes in theoretical loss are obtained with the extremes of antenna heights.

The electrical constants and equivalent slab height obtained here for Area I are considerably different from those obtained by Sachs and Wyatt [1966, 1968] and Sachs [1966] for the same environment. In particular, the σ obtained here is less (0.03 - 0.04 mmhos/m as compared to their 0.09 - 0.15 mmhos/m) and the equivalent slab height is larger (60 feet as compared to their 40 feet). However, with the constants obtained here, the slab model is seen to provide a reasonable model from 2 to 400 MHz, which are the limits of the data utilized in the comparison. The effective slab height, as mentioned, is significant in obtaining the agreement between theory and experiment. However, increasing the effective slab height, in view of the fewer trees extending to the higher height, is contrary to the original model concept (especially at the higher frequencies) requiring closely spaced trees relative to a wavelength, as discussed in the previous section. It is here that the scatter concept, also discussed in the previous section, provides the physical justification for employing the relatively large effective slab heights, and the agreement obtained supports the scatter concept.

Note that the effective electrical constants of the jungle for the Areas I and II are about the same, with the major difference in the slab models of the two areas being in

their effective heights. In view of the significant difference in foliage density of the two environments (Section 2.1), the near equality of the effective electrical constants suggests that changes in the foliage density have little effect. The difference in effective slab height, however, is in qualitative agreement with the difference in tree height for the two environments, i.e., taller trees and larger effective slab height in Area II. The implications are that difference in the tree height may be the dominant factor in specifying environmental differences on forest propagation. This is significant because the tree heights are among the more easily determinable factors of the environment, and suggests the model may be extended to other forest environments with a minimum of knowledge about that environment. The loss is very sensitive to changes in the conductivity, however, and further experimental effort is required to correlate the physical characteristics of the environment with the electrical parameters. The foliage survey presently in progress in Area II should yield data pertinent to such a study. However, it is cautioned that a slab model, or continuum, is not likely to provide insight into the variability of the measurements caused by standing waves.

The significance of standing waves in a forested environment should, perhaps, be further discussed. Standing waves have been known to be present in forested environments for some time [Englund, et al., 1933] and are an inherent part of propagation at the frequencies commonly employed in tactical communications in such environments. Jansky & Bailey [1966] discuss characteristics of the spatial variability in the signal for Area I, which have been related to standing waves [Hicks and Robertson, 1969]. The more important findings by Jansky & Bailey [1966], for present purposes, are that the peak-to-minima ratio of the standing waves may be quite large,

averaging 10 - 15 db for vertical polarization, about 5 db less for horizontal, and increasing with increasing frequency. The average spacing between the peaks and minima along the transmit-receive direction is approximately 0.37λ . The slab model does not account for such variability and cannot, therefore, be used to compute point-to-point signal strengths with any greater accuracy than afforded by the signal variations caused by standing waves. Further, the signal computed from the model can, with equal probability, be expected to exhibit this inaccuracy at, or within a fraction of a wavelength from, the range used in the computation. This does not invalidate the slab model, but further suggests it be extended to include the scattering or reflection from trees which cause the standing waves. Other factors also suggest such an extension.

Paramount among the additional factors to be considered is the fact that the transmission loss behaves differently for horizontally and vertically polarized transmitted waves. We shall discuss the polarization effect in general, and then see how it may be related to a scatter model. Figures 3.3.7 and 3.3.8 show the polarization difference for Areas I and II, respectively, for the frequencies > 25 MHz and equal transmit and receive antenna heights. The lower frequencies are not included in Figures 3.3.7 and 3.3.8 because the transmission loss at the lower frequency may be affected by antenna impedance changes [Dence and Tamir, 1969], and because of the uncertainty of the effective heights to be attributed to the vertical monopole transmitting antennas at these frequencies. Figures 3.3.7 and 3.3.8 show that the transmission loss is generally less for horizontal than for vertical polarization (by as much as 15 to 23 db in some cases) and that this difference decreases with increasing antenna height and frequency and may change sign at the greater heights and frequencies.

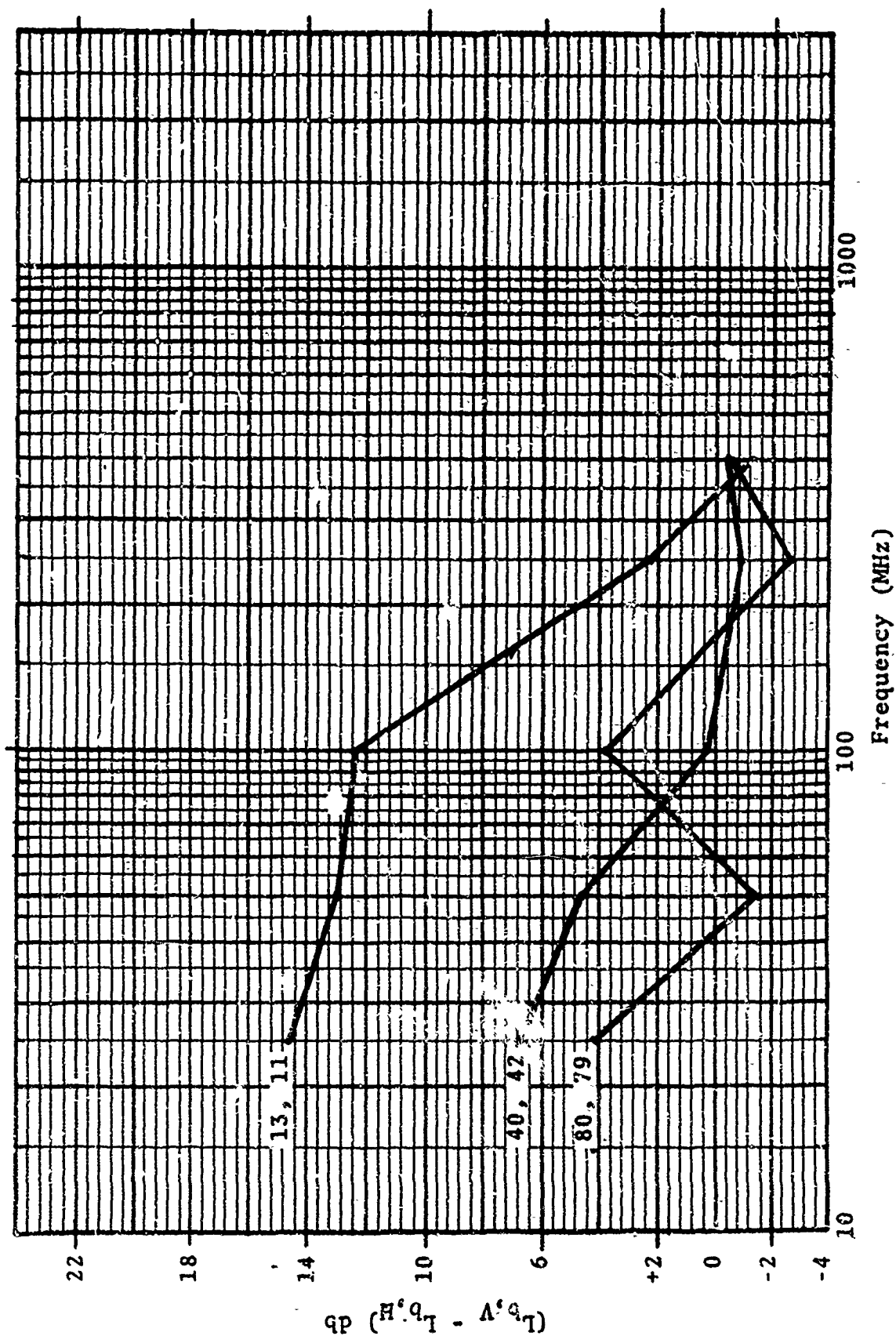


Figure 3.3.7 Difference Between Vertical and Horizontal Polarization, Area I

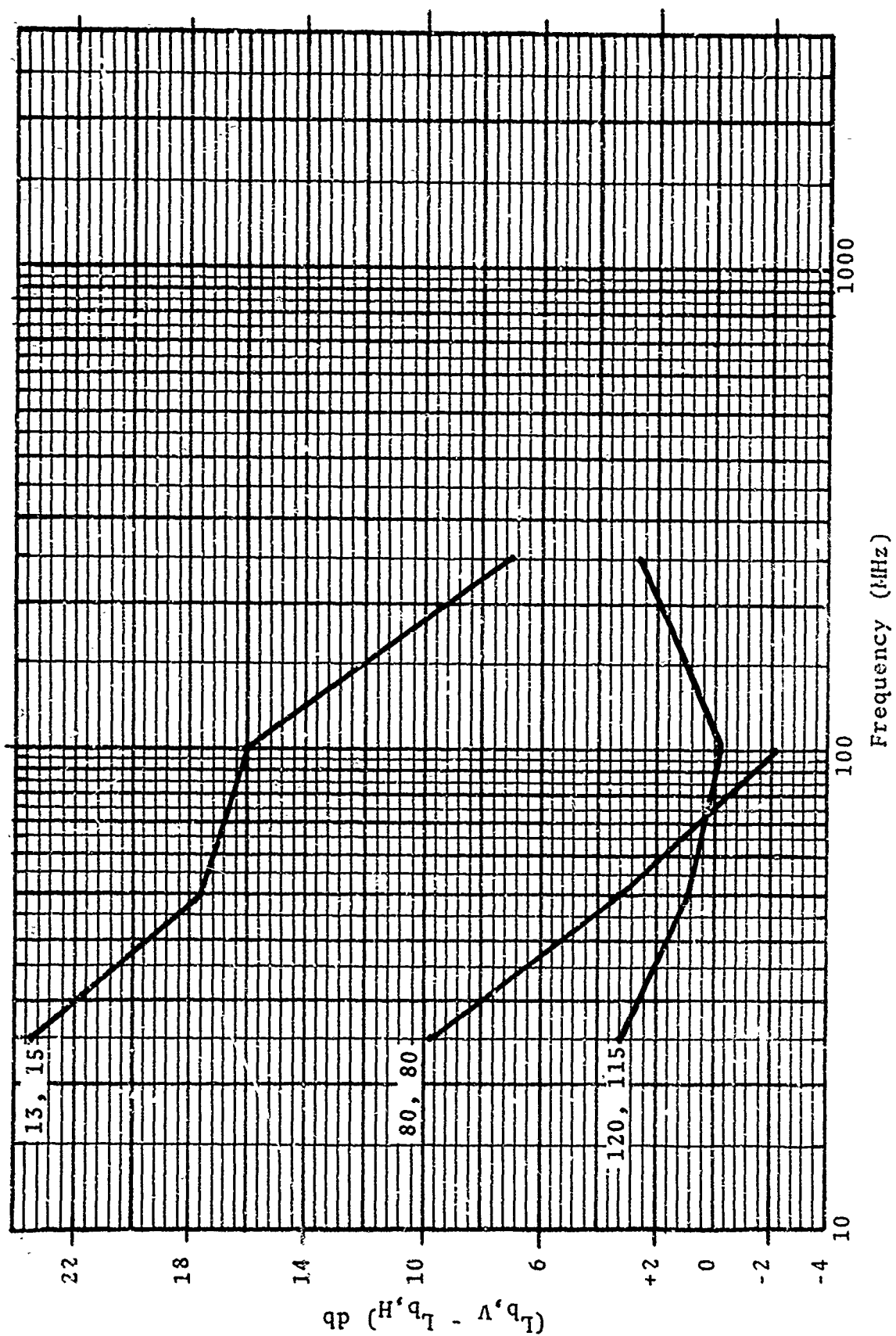


Figure 3.3.8 Difference Between Vertical and Horizontal Polarization, Area II

Also, the polarization difference is generally less in Area I than Area II. The polarization difference in transmission loss may be attributed to two factors: polarization difference in the ground-reflected wave (a lateral wave which becomes negligible as the antennas are far removed from the ground [Sachs and Wyatt, 1966]), and anisotropy of the forest. One can theoretically determine the polarization difference due to the ground reflected wave (using empirical ground and forest electrical properties) [Dence and Tamir, 1969] and subtract this from the total experimentally determined polarization difference to obtain the effect due only to the forest anisotropy. This is presently being investigated, encompassing transmission losses for very low antennas as well. However, it is noted that Dence and Tamir [1969] show that the transmission loss due to the ground reflected wave is generally greater for horizontal than vertical polarization. With this in mind, define ΔL_b as

$$\Delta L_b \equiv L_b \text{ (vertical)} - L_b \text{ (horizontal)}$$

and write

$$\Delta L_b \text{ (total)} = \Delta L_b \text{ (forest)} + \Delta L_b \text{ (ground)}$$

where $\Delta L_b \text{ (total)}$ is the total experimental ΔL_b , $\Delta L_b \text{ (forest)}$ depicts the effect of the forest anisotropy and $\Delta L_b \text{ (ground)}$ depicts the polarization effect of the ground reflected wave. Hence,

$$\Delta L_b \text{ (forest)} = \Delta L_b \text{ (total)} - \Delta L_b \text{ (ground)}.$$

Noting from Figs. 3.3.7 and 3.3.8, however, that $\Delta L_b \text{ (total)} > 0$ in general and that theoretically, from Dence and Tamir [1969], $\Delta L_b \text{ (ground)} < 0$, then

$$\Delta L_b \text{ (forest)} = \Delta L_b \text{ (total)} + |\Delta L_b \text{ (ground)}|.$$

Thus, if the ground has any effect, it will generally result in the forest anisotropy being larger than that indicated by the total experimental ΔL_b . The ΔL_b of Figures 3.3.7 and 3.3.8 may therefore be regarded as conservative estimates of the advantage (less transmission loss) of horizontal polarization over vertical polarization due to the forest anisotropy.

The anisotropy due to the presence of trees, although not well defined, has been known for some time [Trevor, 1940; Jansky & Bailey, 1943; Saxton and Lane, 1955; and others]. The anisotropy in a jungle, however, is generally more serious than that encountered in the, apparently, less dense forests considered by the previous workers, and should not be ignored in general. Sachs [1966] empirically accounts for the anisotropy in the slab model by assuming a larger jungle conductivity for vertical than for horizontal polarization. This procedure has been employed here, as evidenced by the different σ_j given above for horizontal and vertical polarization.

The anisotropy may be associated directly with the scatter and absorption of the trees since it is known that trees scatter more effectively for vertically than horizontally polarized waves [Steele, 1967]. Accepting this, it is intuitively expected that the anisotropy will decrease as frequency increases because the difference in size of the scatterers (trees) for vertical and horizontal polarization, in terms of wavelengths, decreases with increasing frequency. Also, it is intuitively expected that the anisotropy will decrease with increasing antenna height because the propagation path through the forest decreases with increasing antenna height (utilizing the lateral wave concept of propagation up to the forest-air interface, along this interface in the air medium and down to the receiver) and in this reduced path there are relatively

more non-vertical scatterers (limbs). If the number of horizontally oriented scatterers in the path exceeds the vertical scatterers, as may be the case for antennas near the forest-air interface, then it may be expected that the transmission loss for horizontal polarization be greater than for vertical for antennas near the forest-air interface. These intuitive results are in accord with the experimentally obtained anisotropy in Figures 3.3.7 and 3.3.8.

Further evidence that scattering is important may be obtained by examining the standard deviations, σ , of the transmission loss given in Tables 3.3.5 - 3.3.8. For illustrative purposes, the standard deviation, σ , for the configurations given in Figures 3.3.1 and 3.3.2 are plotted in Figures 3.3.9 and 3.3.10. These show, generally, that σ increases with increasing frequency and decreases with increasing antenna height. The former is consistent with the concept that the trees scatter significantly because it is expected that scatter increases as the scatterers become larger in terms of wavelength. The latter is consistent with the scatter concept because the propagation path through the forest medium is shortened, decreasing the number of scatterers, as the antennas approach the forest-air interface. It appears that σ is larger for vertical than horizontal polarization in general, but this difference is relatively small in most cases.

Consideration of the standing wave and anisotropic character of the data suggests, therefore, that an extension of the slab model to include scattering and absorption by the trees would more nearly represent the observed behavior. Further, because the scattering increases with frequency, such a model would conceivably be applicable at the higher frequencies important to radar applications. Such a development would

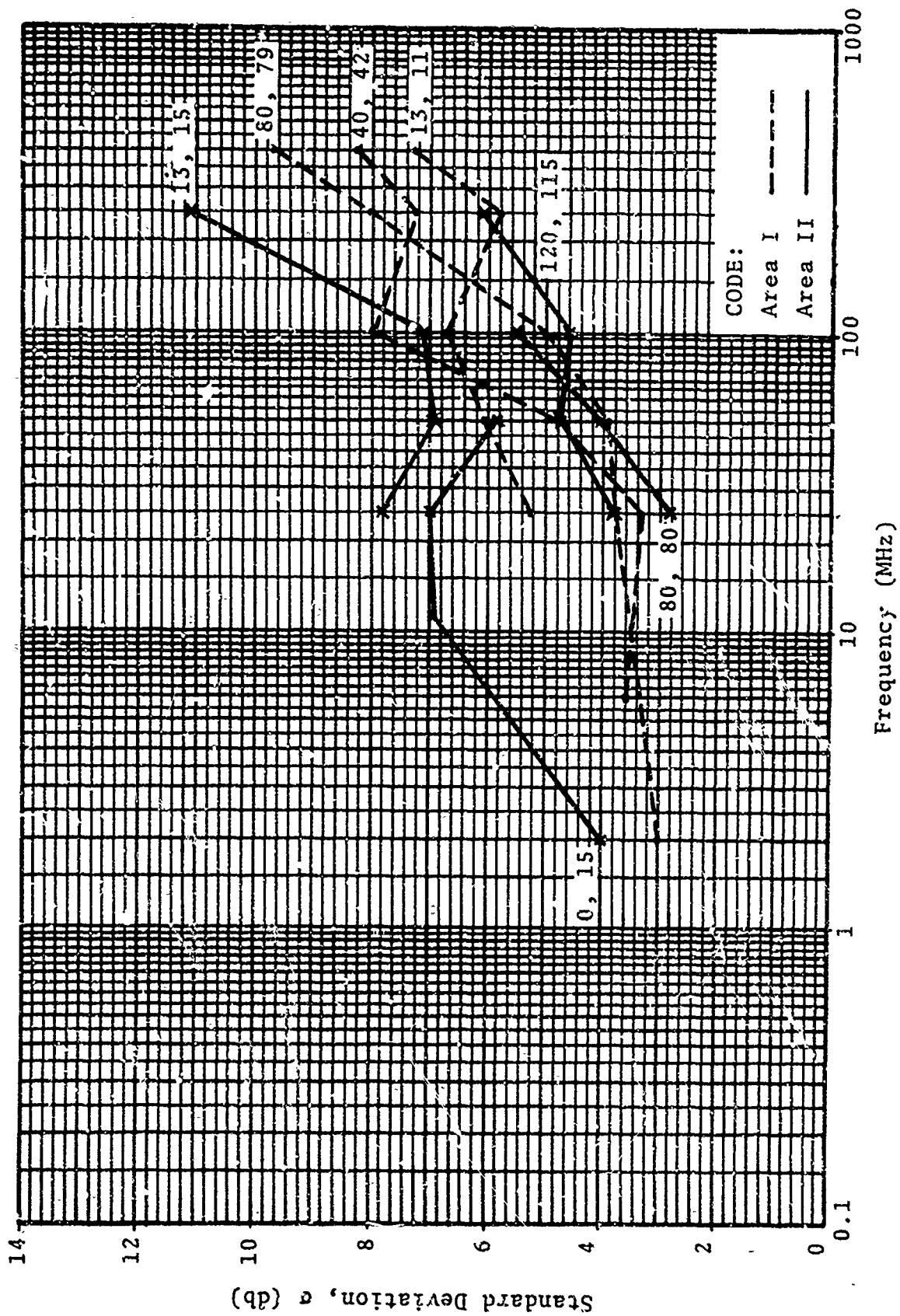


Figure 3.3.9 Comparison of Standard Deviations in Areas I and II, V Polarization

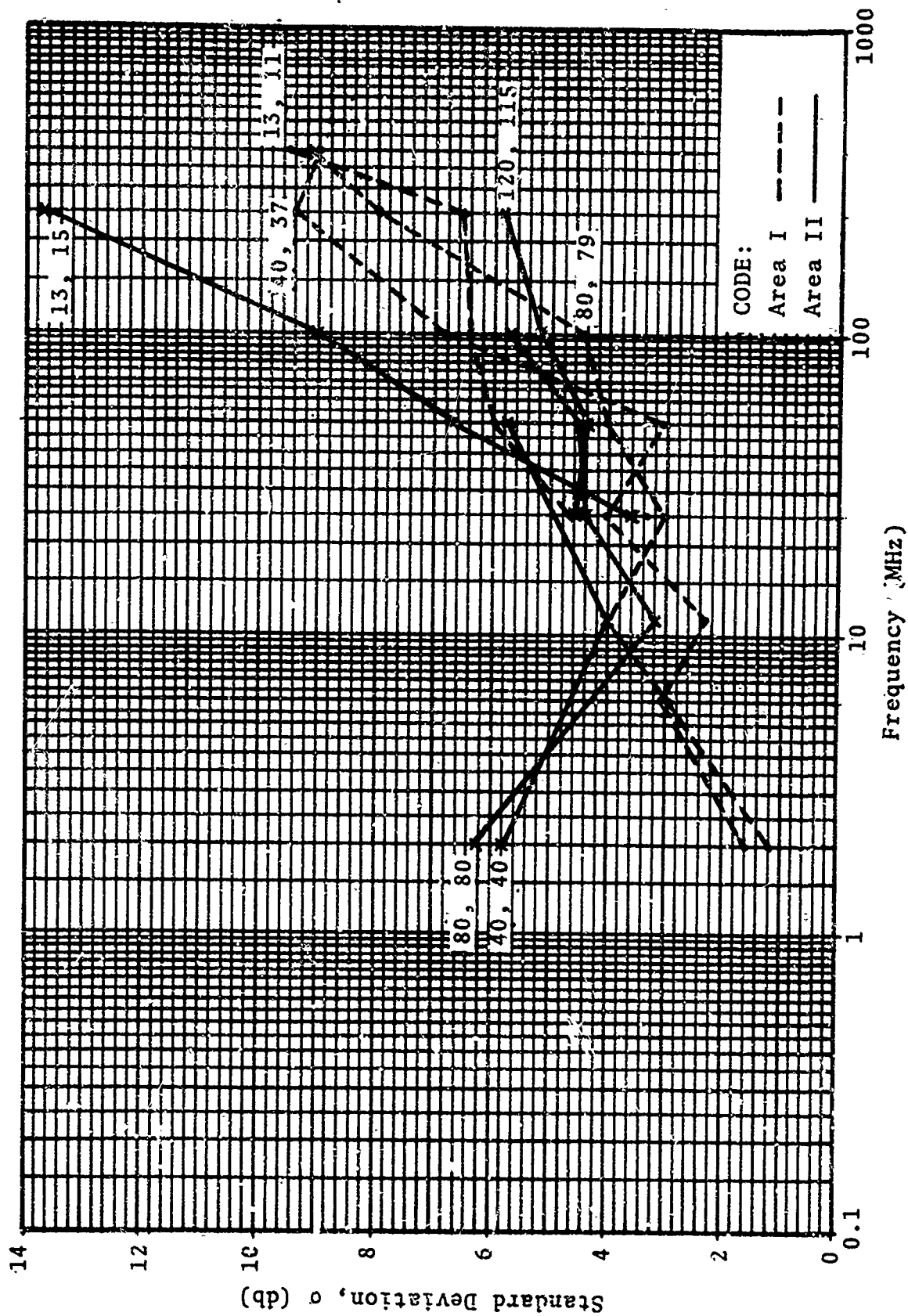


Figure 3.3.10 Comparison of Standard Deviations in Areas I and II, H Polarization

also be beneficial to mobile communications in general and to digital and wideband operations, as these may be adversely affected by the multipaths due to scatter from the trees.

3.4 Conclusions

The basic transmission loss at frequencies of 2 to 400 MHz, obtained over fairly smooth terrain in two forested jungle environments of Thailand, increases as $40 \log(\text{range})$, decreases with increasing antenna height, and increases with increasing frequency. This general behavior is consistent with the theoretical lateral wave concepts when the jungle is assumed to be a uniform conducting slab bounded above by air and below by ground. Employing the slab model, reasonable agreement between theoretical transmission loss and mean values of experimental transmission loss is obtained over the frequency range of 2 to 400 MHz with effective electrical constants of the ground (subscript g) and jungle (subscript j) of $\epsilon_g = 15$, $\epsilon_j = 1.01$, $\sigma_g = 19 \text{ mmhos/m}$, $\sigma_j = 0.04 \text{ mmhos/m}$ for horizontal and 0.05 mmhos/m for vertical polarization in Area I, $\sigma_j = 0.03 \text{ mmhos/m}$ for horizontal and 0.04 mmhos/m for vertical polarization in Area II, and the effective slab height is $h = 60 \text{ feet}$ and $h = 100 \text{ feet}$ for Area I and Area II, respectively.

The vegetation biomass is greater in Area II than Area I. The effective electrical constants of the two areas are about the same, however, which indicates small, if any, correlation between vegetation biomass and effective electrical constants. The effective slab height and the tree heights are directly correlated, however, being greater for Area II. This suggests that it may be possible to extend the slab model to different forested environments with a more limited

knowledge about the environment than has been anticipated. Small changes in the effective conductivity of the slab model are significant, however, and further work is required to more exactly associate the environmental features to the model parameters.

The slab model concept, however, appears to require modification or extension to a scatter model to explain the spatial variability in the signal. The spatial variability caused by standing waves places a basic limitation to the applicability of the slab model in predicting point-to-point field strength or path loss in the forested environment.

Extension of the model to include scattering is also suggested by characteristics of the anisotropy of the jungle environment and the standard deviations of the basic transmission loss. The forest anisotropy, which results in less loss for horizontal than vertical polarization, by as much as 15-23 db in some cases, decreases with increasing antenna height and frequency. The standard deviation increases with increasing frequency and decreasing antenna heights. These are consistent with known scatter properties of trees, but further work is required to analytically develop the scatter model.

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4. TRANSMISSION LOSS OVER JUNGLE-TO-AIR PROPAGATION PATHS

A considerable amount of experimental and theoretical effort has been devoted to understanding propagation in foliated jungle environments [Herbstreit and Crichlow, 1964; Whale, 1968; Jansky & Bailey, 1962-1969; Sachs and Wyatt, 1966, 1968; Sachs, 1966; Tamir, 1967; Dence and Tamir, 1969]. This effort, however, has been focused primarily on the case of ground based antennas, located in and just above the foliage medium. Communications, navigational, direction finding and other requirements in jungle environments may also require propagation over air-to-jungle links. Sachs [1969] has theoretically treated the general case, for antennas at any height, when the jungle can be assumed a uniform conducting slab bounded above by air and below by ground. The model has been applied in Section 3 and found to satisfactorily describe the mean transmission loss for antennas located in and just above the jungle environment, but it has not been tested for the general jungle-to-air propagation link. The purpose of this section is to present and discuss the experimental values of transmission loss obtained over jungle-to-air paths, and compare these results with the theory based upon the uniform conducting slab model of the jungle.

Experiments were conducted at frequencies of 25, 50, 100, 250, and 400 MHz, using a helicopter or a fixed-wing aircraft to carry the receiving test equipment. Signals were transmitted from horizontally and vertically polarized antennas at various heights above ground in the jungle vegetation in Test Area II. The environment of Area II is discussed in Section 2 of this report and in Semiannual Report Number 9. Experimental procedures are discussed next, followed by a brief

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outline of the theory. The experimental data are then presented, compared with theory, and conclusions drawn.

After presenting a brief theoretical background of the slab model when one antenna is high above the jungle vegetation, the experimental procedures for the air-to-ground measurements are discussed, followed by a comparison of experimental and theoretical results. The conclusions drawn from this phase of the work are then presented.

4.1 Theoretical Background

The theoretical field strength, calculated with the slab model for one antenna high above the jungle vegetation, differs from the results obtained when both antennas are confined to be within or just above the foliage [Sachs and Wyatt, 1966; Sachs, 1966]. Such a case is illustrated in Figure 4.1.1, and Sachs [1969] has treated this case as well as those for the lower antennas referenced above and discussed in Section 3.

Employing the MKS system of units, the measurable electric field for the case of one antenna high above the foliage (i.e., $z > \sqrt{r/k} + H$) is given by Sachs [1969] as:

$$E = \frac{9 \times 10^4 \sqrt{P} (z - H)}{\sqrt{2} \pi f r^2} F(z, z_0) \text{ v/m} \quad (4.1.1)$$

where

$$F(z, z_0) = \left| \frac{e^{ix_j k (z_0 - H)} \left(1 + V_g e^{-2ix_j k z_0} \right)}{ix_j (1 + x_a/A_j) \left(1 - V_a V_g e^{-2ix_j k H} \right)} \right| ; 0 < z_0 < H$$

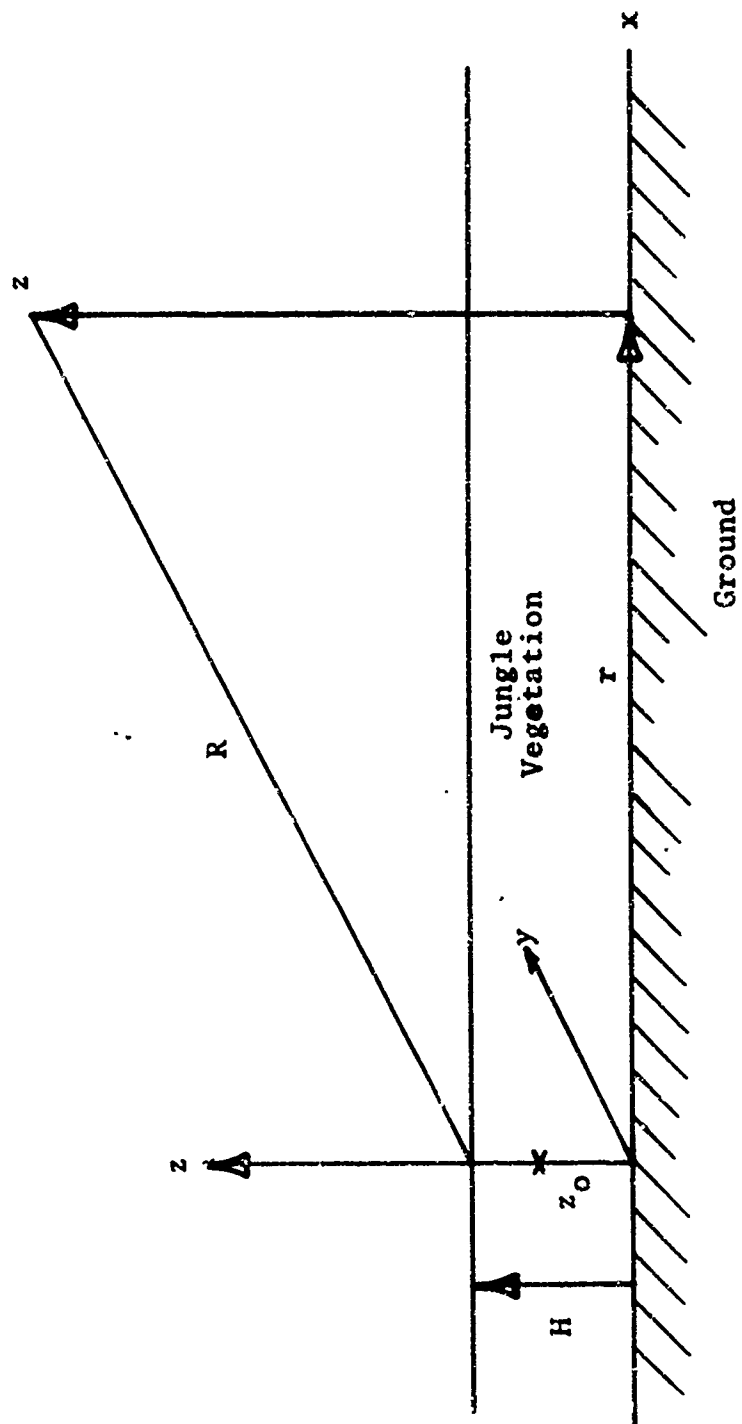


Figure 4.1.1.1 Slab Model Geometry For One High Antenna

and

$$F(z, z_0) = \left| \frac{e^{x_a k(z_0 - H)} - e^{-x_a k(z_0 - H)}}{2x_a} + \frac{e^{-x_a k(z_0 - H)} \left(1 + V_g e^{-2ix_j kH} \right)}{(A_j + x_a) \left(1 - V_a V_g e^{-2ix_j kH} \right)} \right|, \quad 0 < k(z_0 - H) < \sqrt{rk}$$

where η_p is the complex refractive index, P is transmitted power in kilowatts, f is frequency in megahertz, and k is the wave number.

$$x_a = \sqrt{\eta_p^2 - \alpha^2}, \quad \alpha = \frac{r}{R},$$

$$V_a = \frac{A_j - A_a}{A_j + A_a}, \quad V_g = \frac{A_j - A_g}{A_j + A_g},$$

$$A_p = ix_p / \eta_p^2 \text{ for vertical polarization,}$$

$$A_p = ix_p \text{ for horizontal polarization}$$

where $p = j, a, \text{ or } g$, for jungle, air, or ground, respectively, and indicates that the appropriate constants should be applied for these media. These relations, and those of Section 3, are employed in Section 4.3 to obtain the theoretical transmission loss for comparison with experimental data, but before presenting the results the experimental procedures will be discussed.

4.2 Experimental Procedures

The air-to-ground propagation measurements were conducted in the rain forest test area, identified as Area II. The environment of this area has been discussed in Section 2 of this report, as well as in Semiannual Report Number 9. However, as mentioned in Section 2, a more complete forest survey remains to be accomplished before the jungle vegetation can be more exactly characterized.

The same basic transmitter and receiver calibrating procedures used in the other path loss measurements [Jansky & Bailey, 1966] were used in the air-to-ground measurements. The receiver was installed on either a helicopter or a single-engine STOL aircraft, with the receiving antenna rigidly mounted on a shaft extending a few feet below the aircraft. The correction factors necessary to convert measured field strength at the aircraft antenna were obtained by separate calibrations with the antenna mounted on the aircraft, flying at operational altitudes around a calibrated ground antenna which was elevated to 200 feet or approximately 80 feet above treetop level.

During the experimental measurements, the transmitting antenna was located in the vegetation and positioned at various heights above ground. The procedure was to fly the aircraft along prescribed radials toward or away from the transmitter, at a fixed altitude and speed, and to measure the field strength as a function of slant range. The slant range was determined by means of field-fabricated transponder system, with the transponder located on the aircraft. The transponder system transmitted a signal to the aircraft on a frequency separate from those used for measurement. Using an oscilloscope to read the pulse transit time, accuracies on the order

of ± 25 feet were obtained at ranges of 5,000 feet, or less, and at a range of 10,000 feet accuracies of about 1/2 percent were obtained.

The transmitting antennas were half-wave dipoles at each frequency, and the antenna height above ground was referenced to the antenna feed point. The receiving antenna at 25 and 50 MHz was a small loop, and for the frequencies equal to and greater than 100 MHz half-wave dipoles were used. The horizontal antennas were oriented with their theoretical maximum gains along the line between the transmitter and the aircraft. The vertically polarized antennas were mounted to have the maximum gains in the horizontal plane through the antennas. Measurements were not made at slant ranges less than 1,000 feet, however, and the small correction for the vertically polarized antennas not being aligned for their maximum gain along the line of slant range was assumed to be negligible. This is reasonable since the highest elevation angle involved in the measurements was about 30° .

Figure 4.2.1 is a tree diagram of the combinations of frequency, polarization, transmitting height, aircraft altitude (receiving antenna height), and the direction of the radial referenced to true North from the transmitter. The figures in which the experimental data are presented in the next section are referenced in this tree diagram.

4.3 Data Analysis and Discussion

With the aid of a computer, the field strength measurements were reduced to basic transmission loss for isotropic antennas. The basic transmission loss was theoretically computed for the various frequencies, antenna heights,

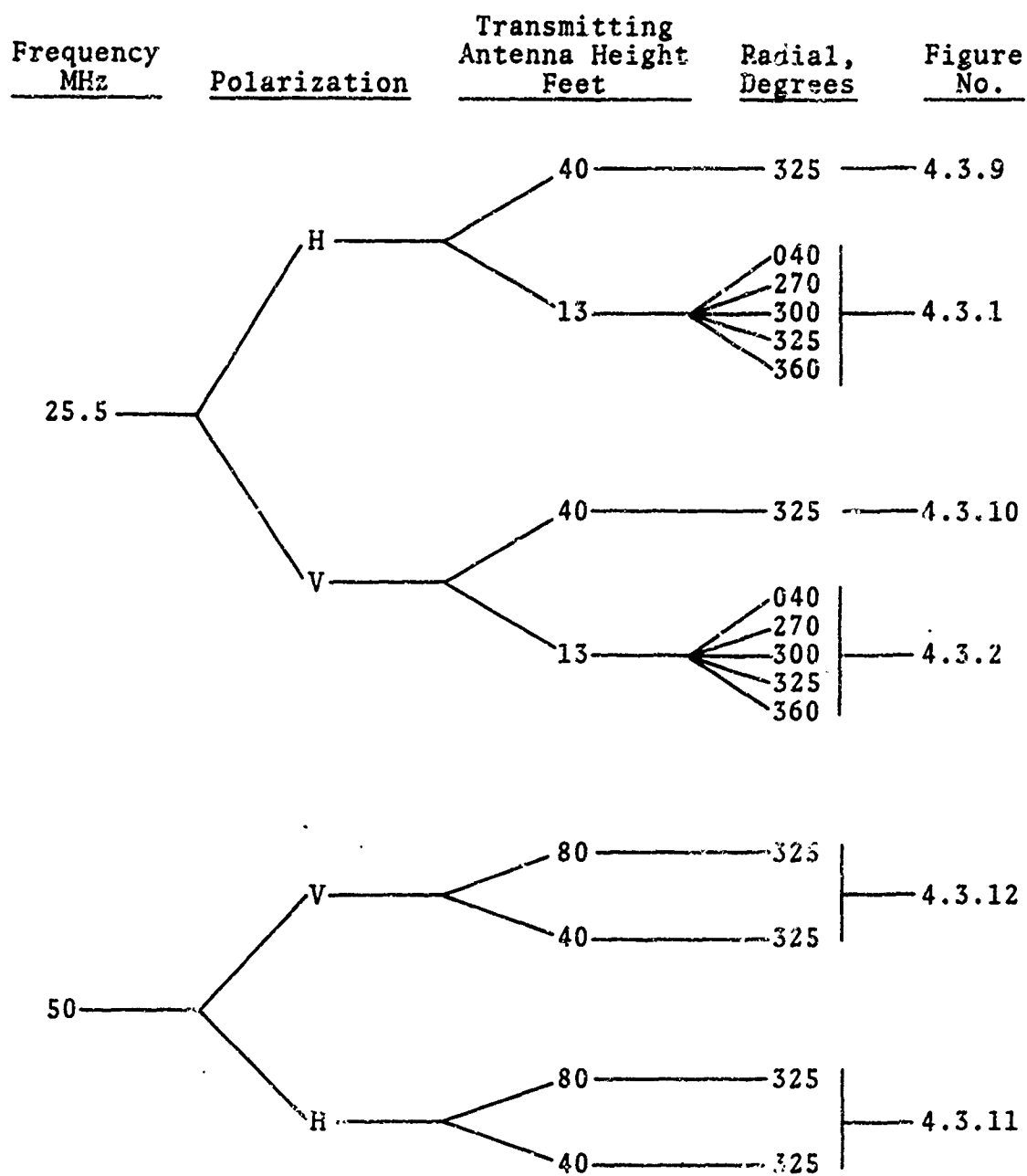


Figure 4.2.1 Tree Diagram of Air-to-Ground Measurements

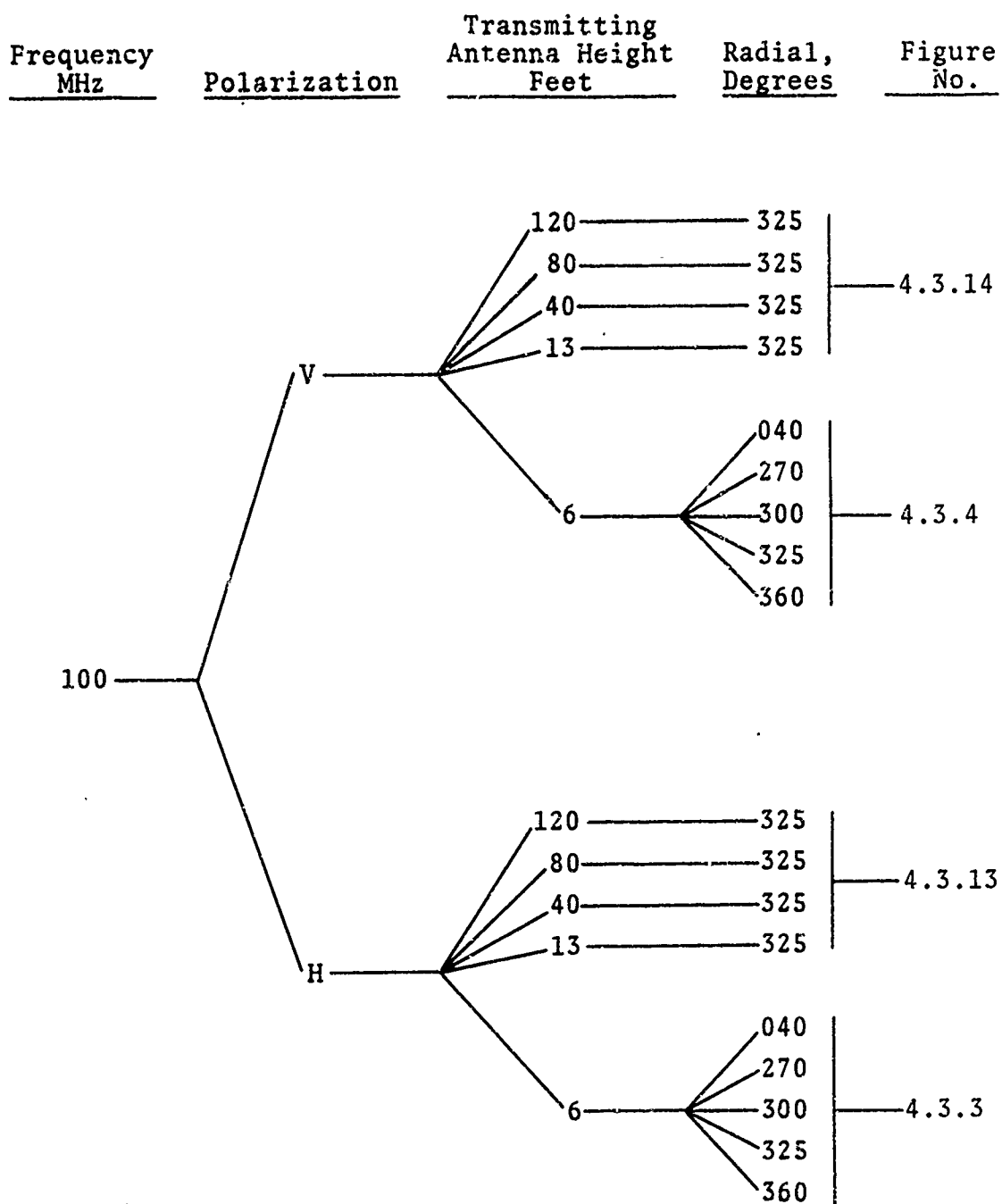


Figure 4.2.1 (continued)

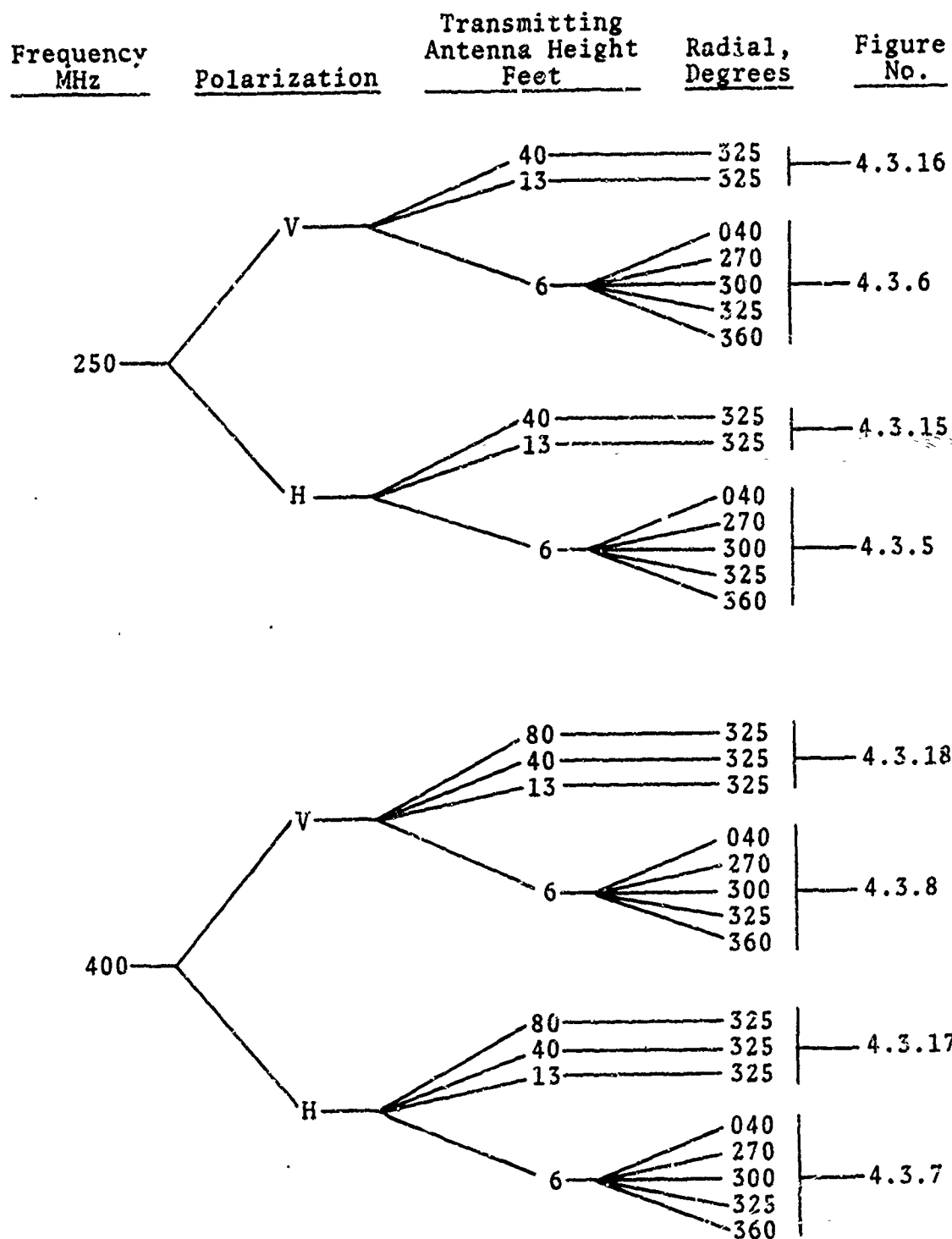


Figure 4.2.1 (continued)

polarizations and ranges given in Figure 4.2.1, using the slab model and electrical parameters obtained in Section 3 for Area II.

Figures 4.3.1 to 4.3.8 show the experimental loss as a function of range for the different flight radials, the corresponding theoretical loss computed from the slab model and, for a convenient reference, the theoretical free space loss. The experimental loss is seen to vary 10 to 15 db between the various radials with no apparent trend (i.e., none of the radials appear to be favored at all frequencies or for either polarization). The transmission loss may be seen to be larger for vertical polarization than for horizontal with the difference, or anisotropy, decreasing with increasing frequency. The experimental loss is also quite variable with range, with the variability increasing with increasing frequency. This variability, both with range as a function of frequency and from radial to radial, and the anisotropy can intuitively be associated with scatter by the trees. The signal variability and the anisotropy behave with frequency in a manner similar to that for ground-to-ground terminals which have been related to tree scatter in Section 3. The variation from radial to radial may also be due to scatter from trees in the vicinity of the transmitter, or multipaths, which differ, due to the random nature of tree size and spacing, with the different directions of propagation (flight radials). It is also possible that the forest medium may differ with different directions of propagation when viewed as a uniform conducting slab, and thereby cause the loss to vary with direction of propagation. This, however, does not appear to be the cause of the observed difference in loss from radial to radial because, if it were, the difference would be expected to be fairly consistent.

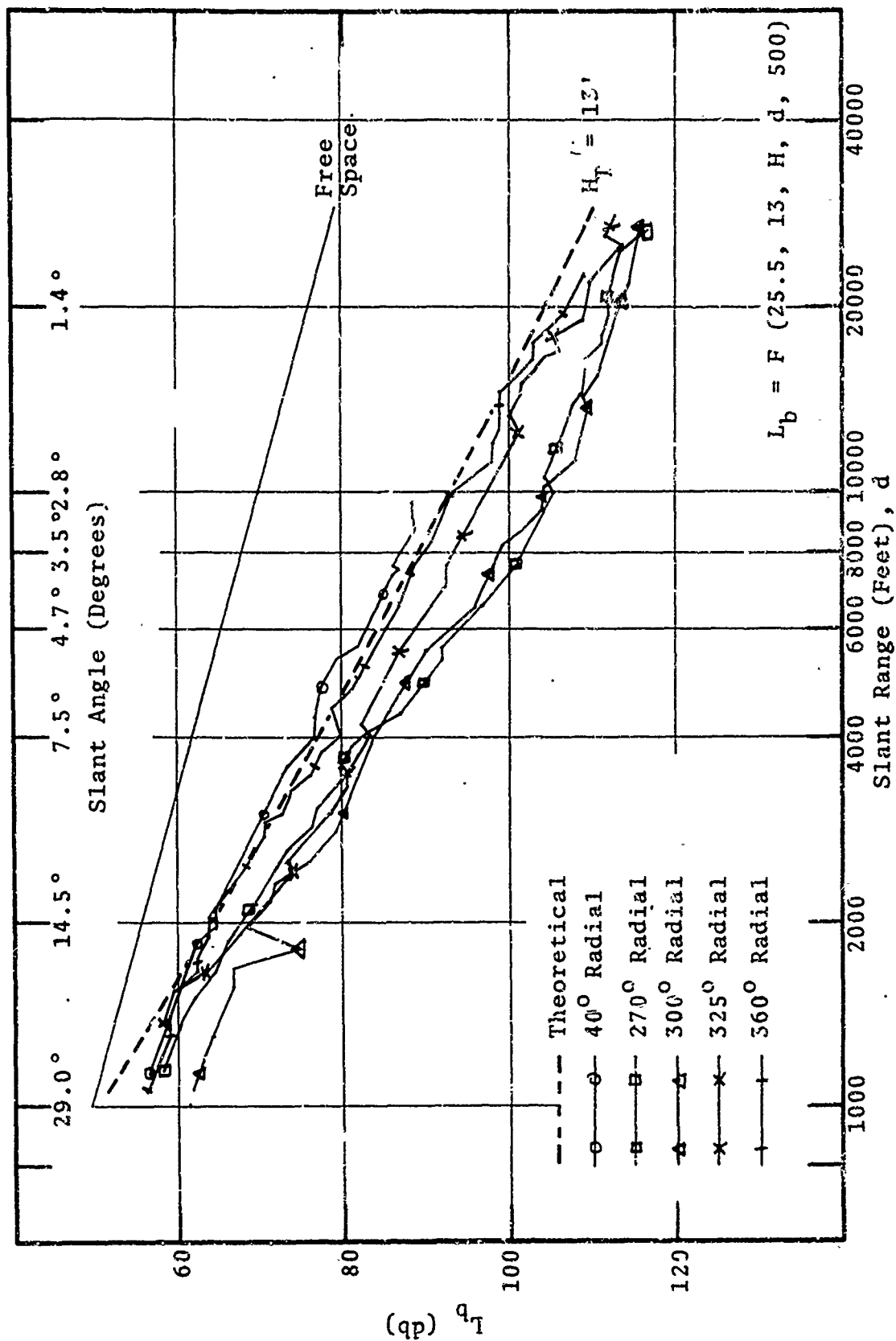


Figure 4.3.1 Comparison of L_b vs. Distance Along Various Radial, Jungle-to-Air Paths

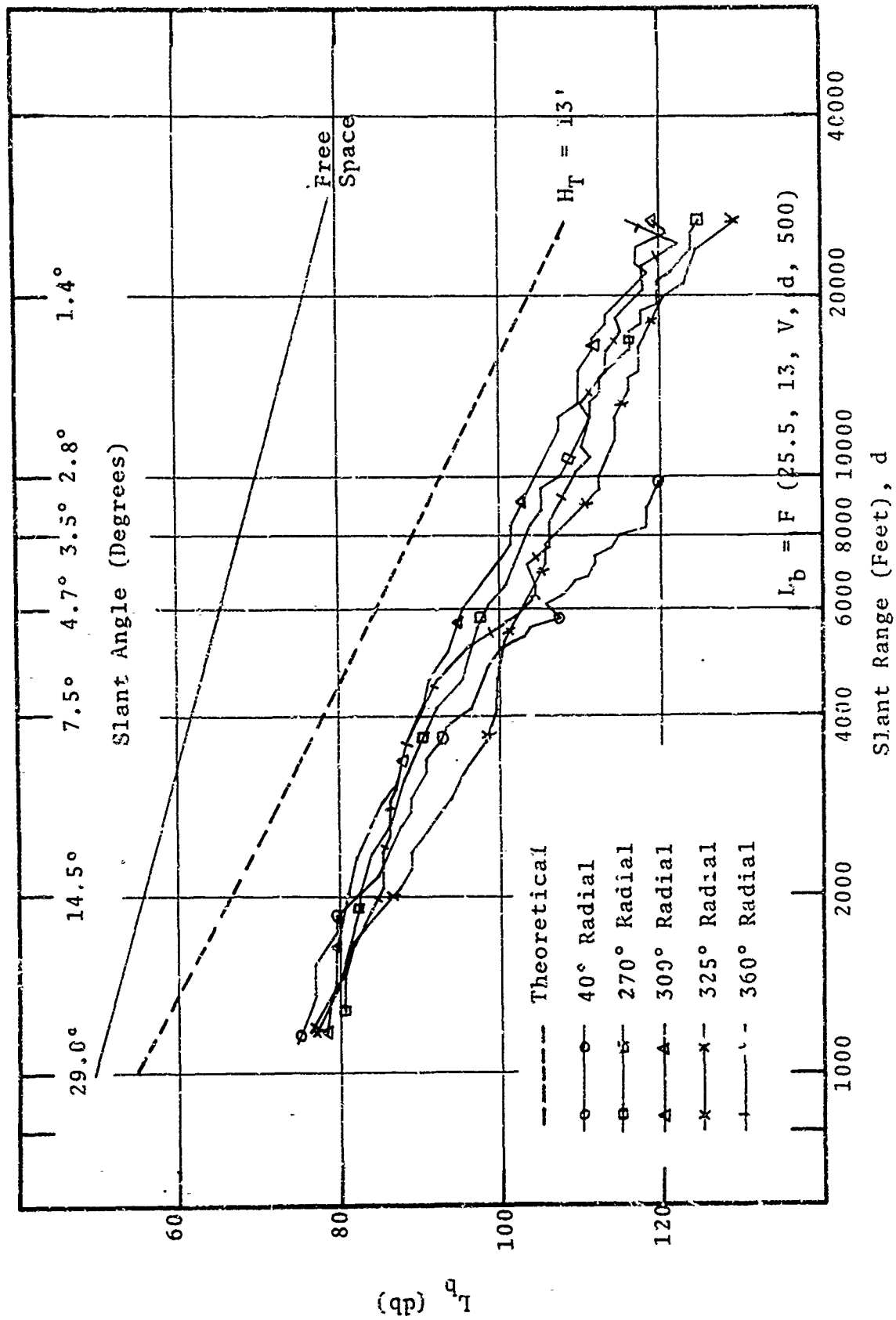


Figure 4.3.2 Comparison of L_b vs. Distance Along Various Radials, Jungle-to-Air Paths

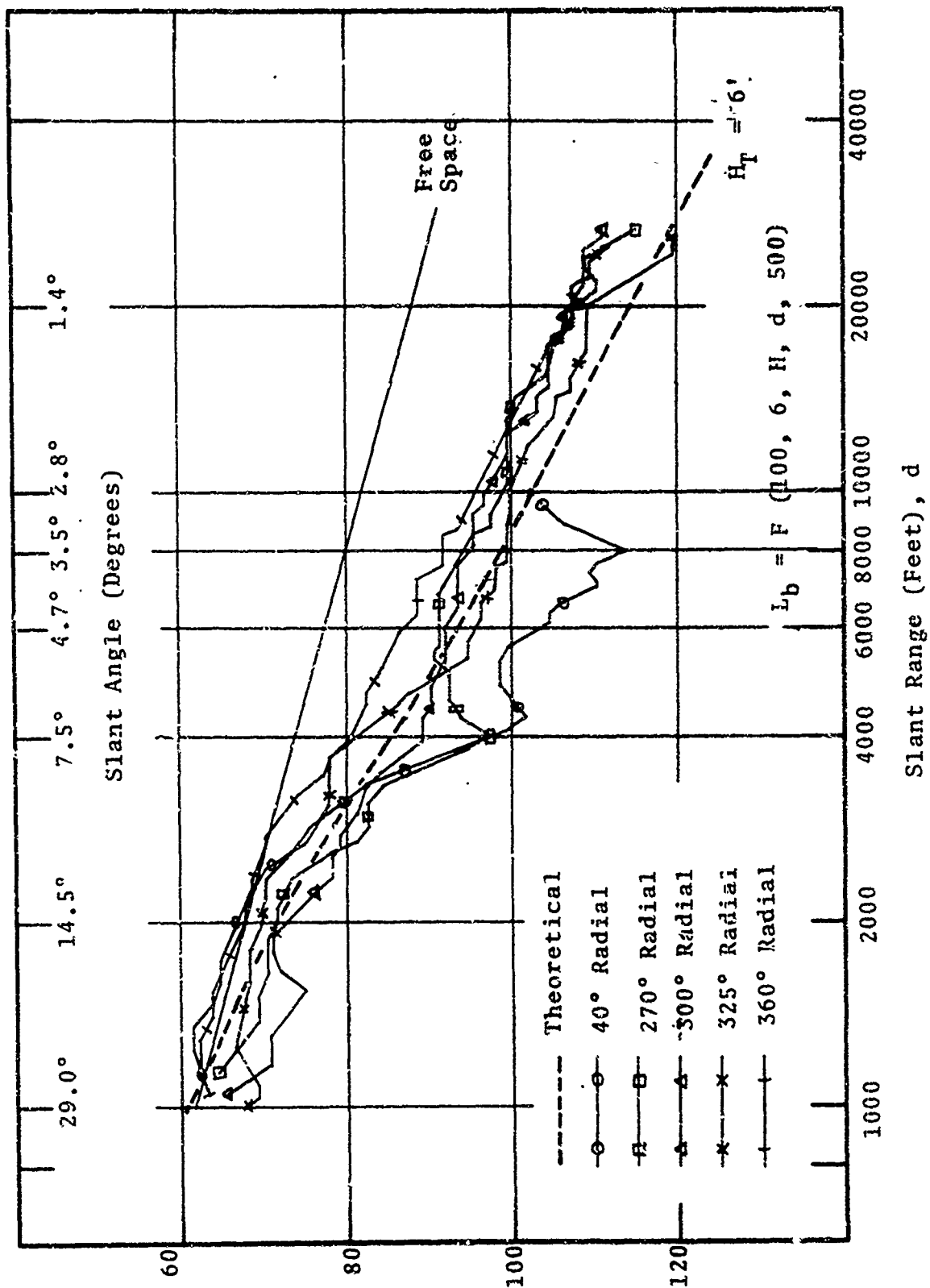


Figure 4.3.3 Comparison of L_b vs. Distance Along Various Radials, Jungle-to-Air Paths

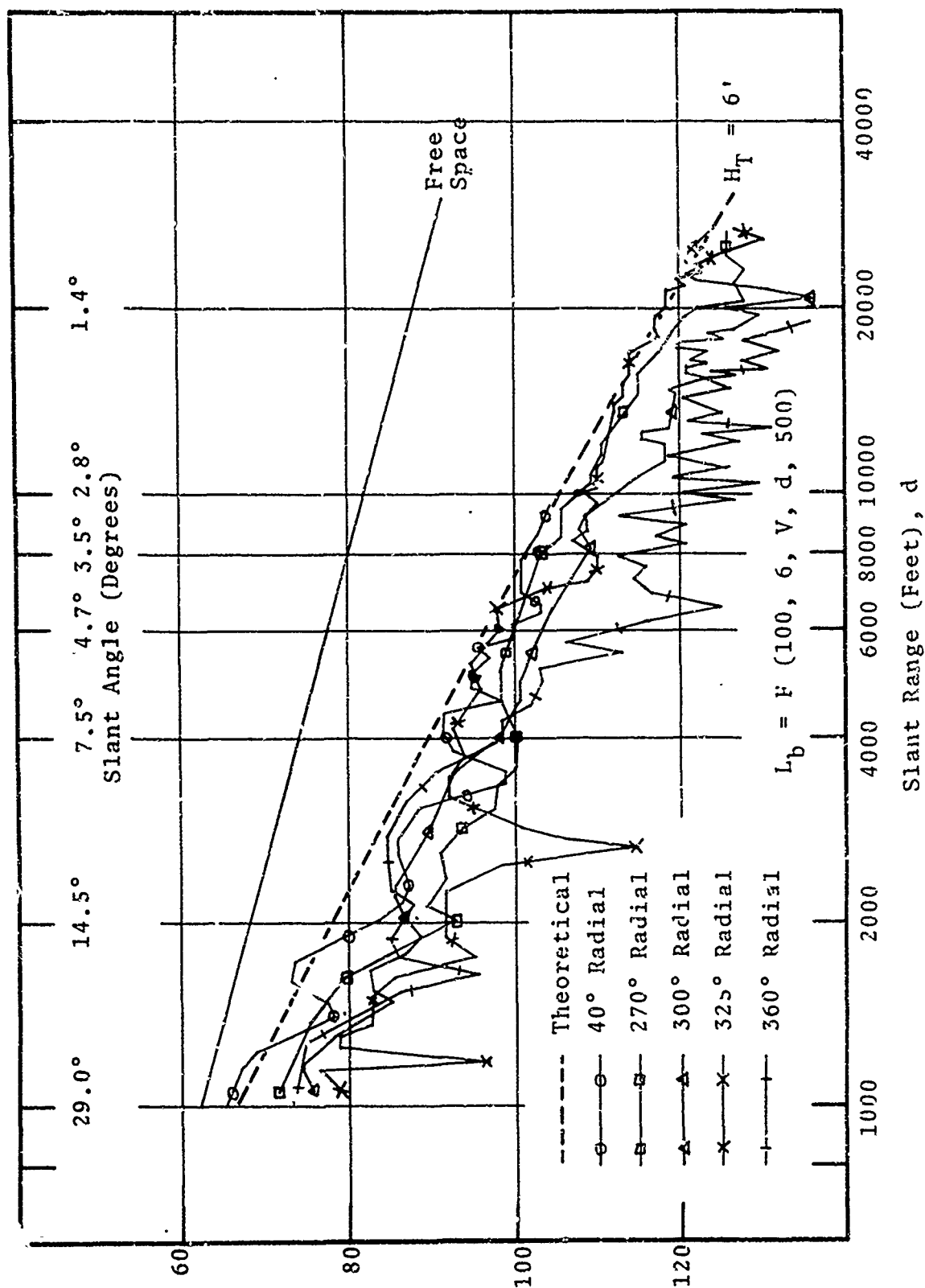


Figure 4.3.4 Comparison of L_b vs. Distance Along Various Radials

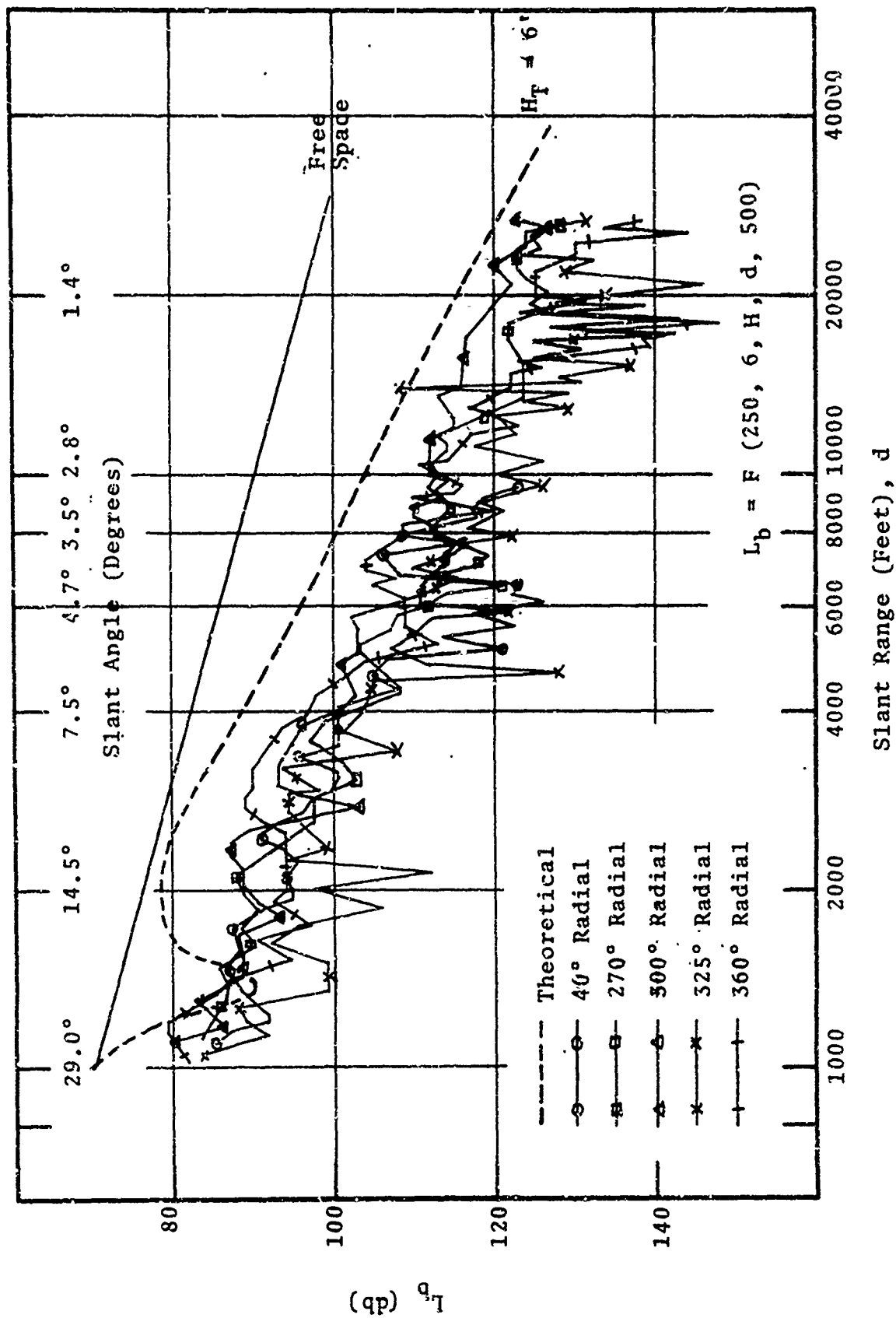


Figure 4.3.5 Comparison of L_p vs. Distance Along Various Radials

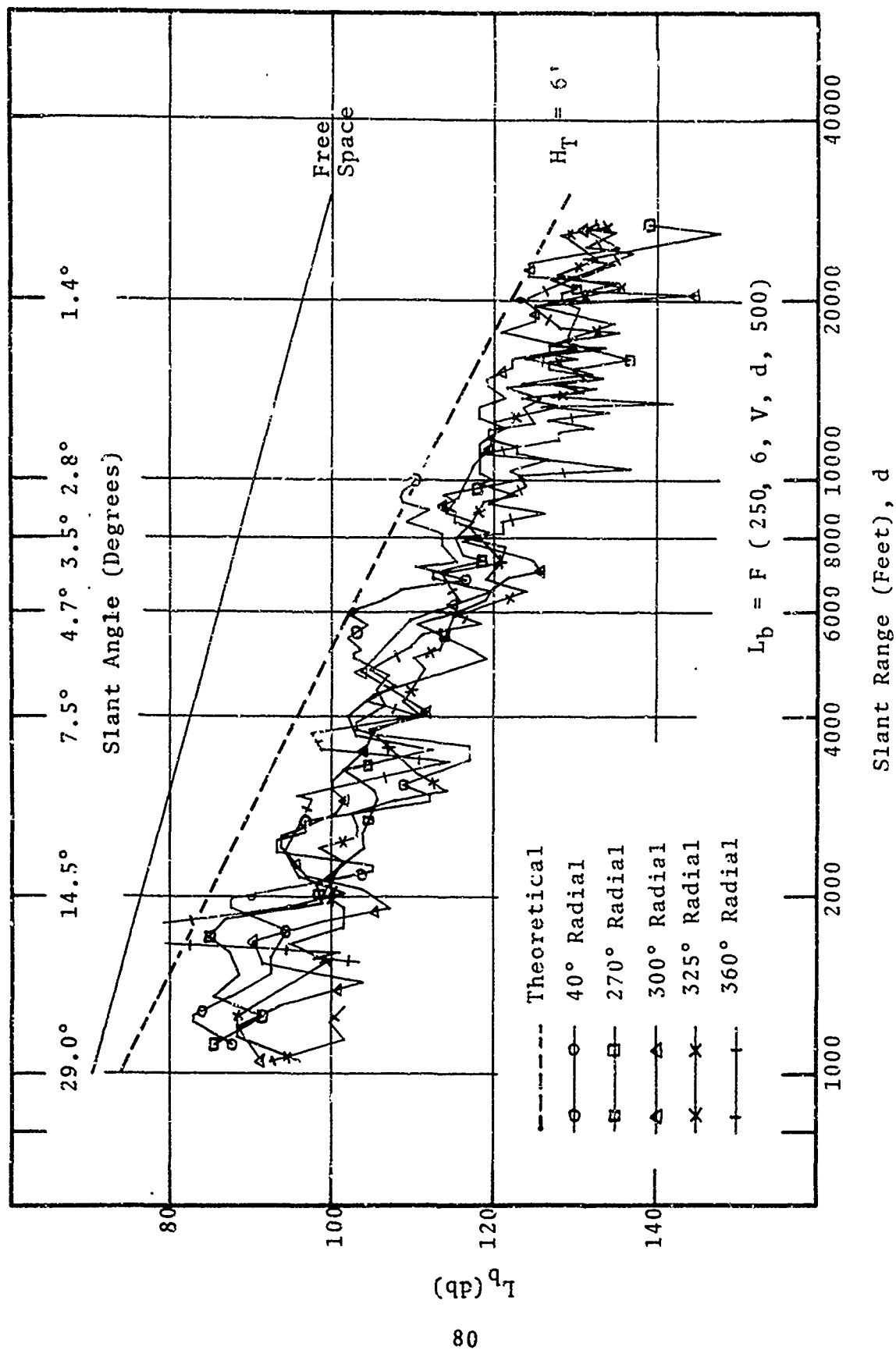


Figure 4.3.6 Comparison of L_b vs. Distance Along Various Radials

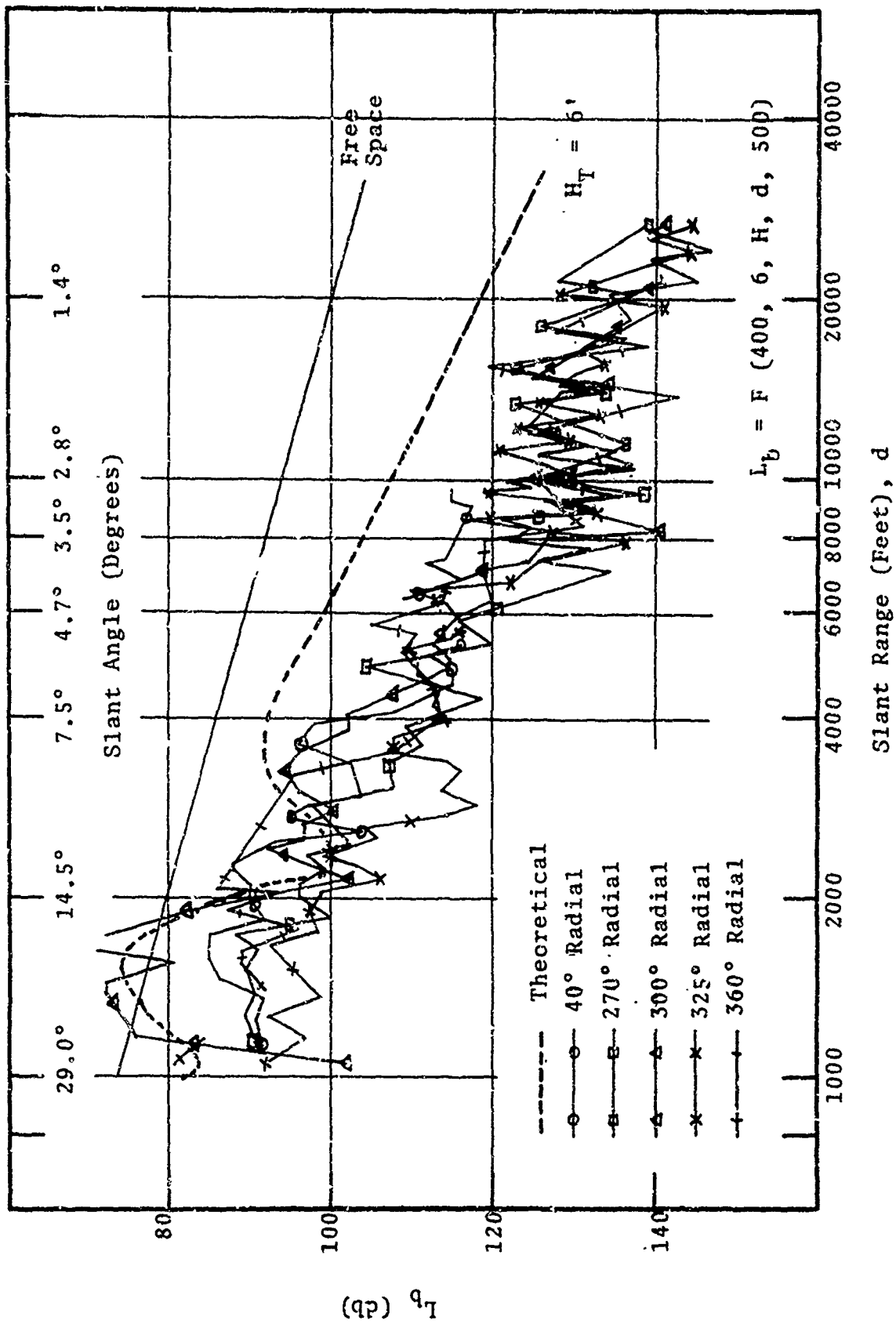


Figure 4.3.7 Comparison of L_p vs. Distance Along Various Radials

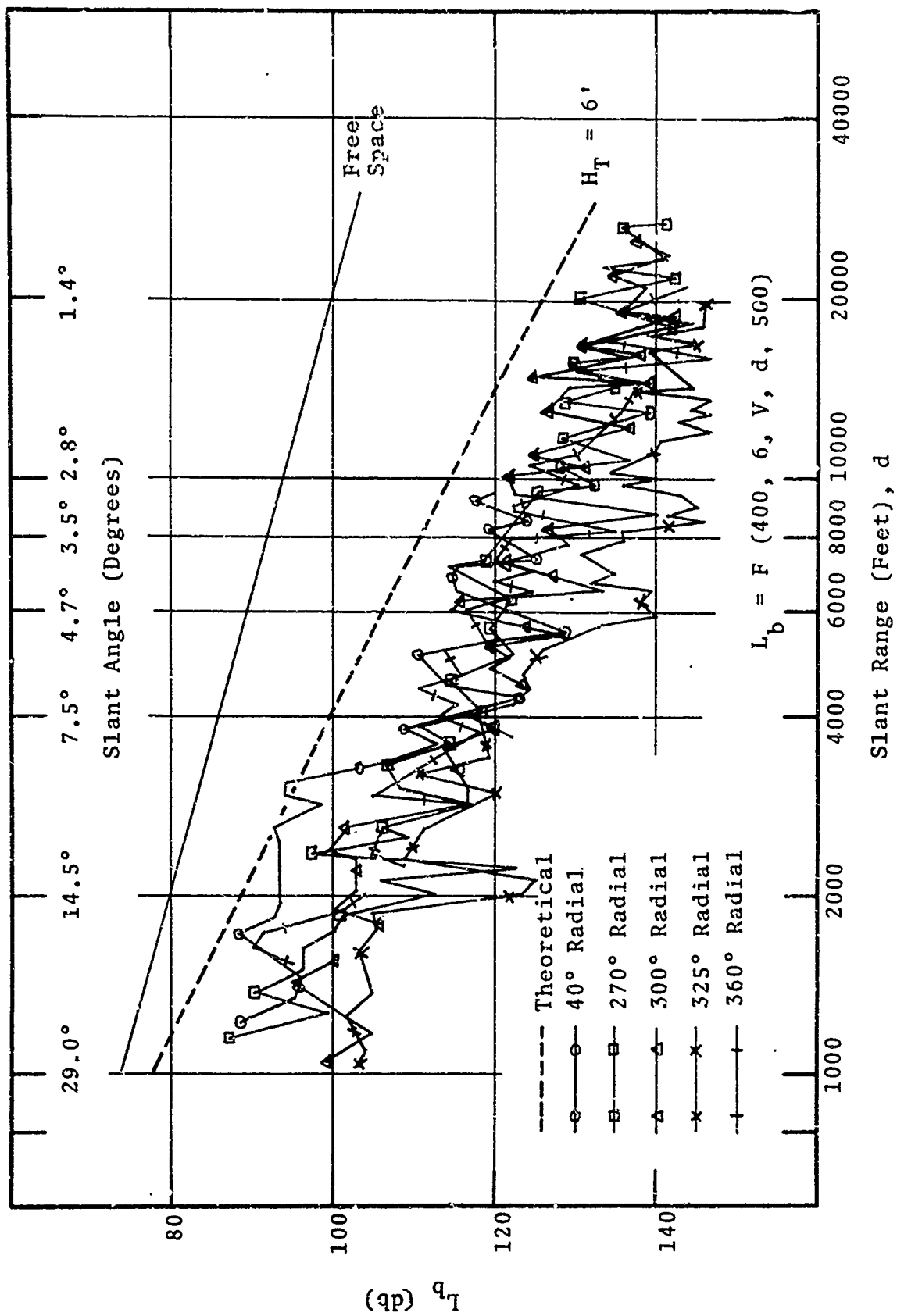


Figure 4.3.8 Comparison of L_b vs. Distance Along Various Radials

The theoretical basic transmission loss in Figures 4.3.1 to 4.3.8, obtained from the uniform slab model, agrees fairly well with the experimental data, but it is generally less than the average experimental loss by a few decibels. The largest error is obtained at 25 MHz for vertical polarization and low transmitter antenna height which, from Figures 3.3.5 and 3.3.6, can be seen to be consistent with the largest error obtained in arriving at the slab constants employed here.

Figures 4.3.9 to 4.3.18 show the experimental and theoretical basic transmission loss for various transmitter antenna heights as a function of slant range. The free space, referenced to the radiated power, is also shown for reference. Generally, the experimental loss decreases with increasing antenna height, but the pronounced variability in the data at the higher frequencies tends to obscure the height dependence there. The anisotropy is also evident in these figures and generally decreases with increasing transmitter antenna height. The theoretical basic transmission loss of Figures 4.3.9 to 4.3.18 also decreases with increasing transmitter antenna height and, as in Figures 4.3.1 to 4.3.8, is generally a few decibels less than the experimental loss with the largest error again at 25 MHz.

As in Section 3 for ground-to-ground terminals, the error would be reduced here for jungle-to-air propagation if a set of electrical parameters and heights for the slab model which vary with frequency had been employed. This improved slab model would still not account for the variability in the loss with range and from radial to radial. Hence, as in Section 3, a refinement of electrical parameters and heights for the slab model does not appear to be warranted at this stage. While the slab model may be employed to predict the mean transmission loss, generally to within a few db of the

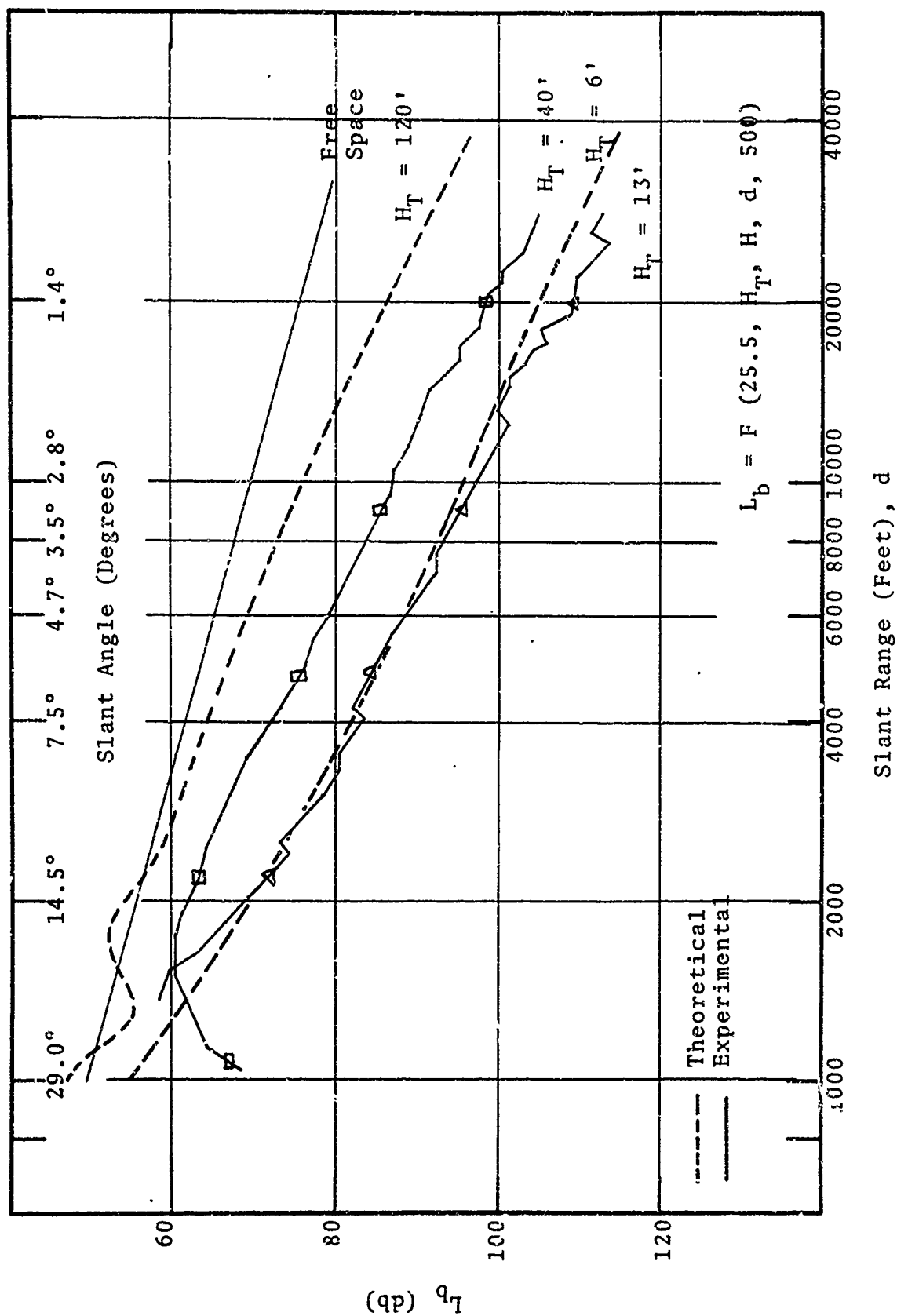


Figure 4.3.9 Comparison of L_b vs. Distance Along 325° Radial For Various Transmitting Antenna Heights

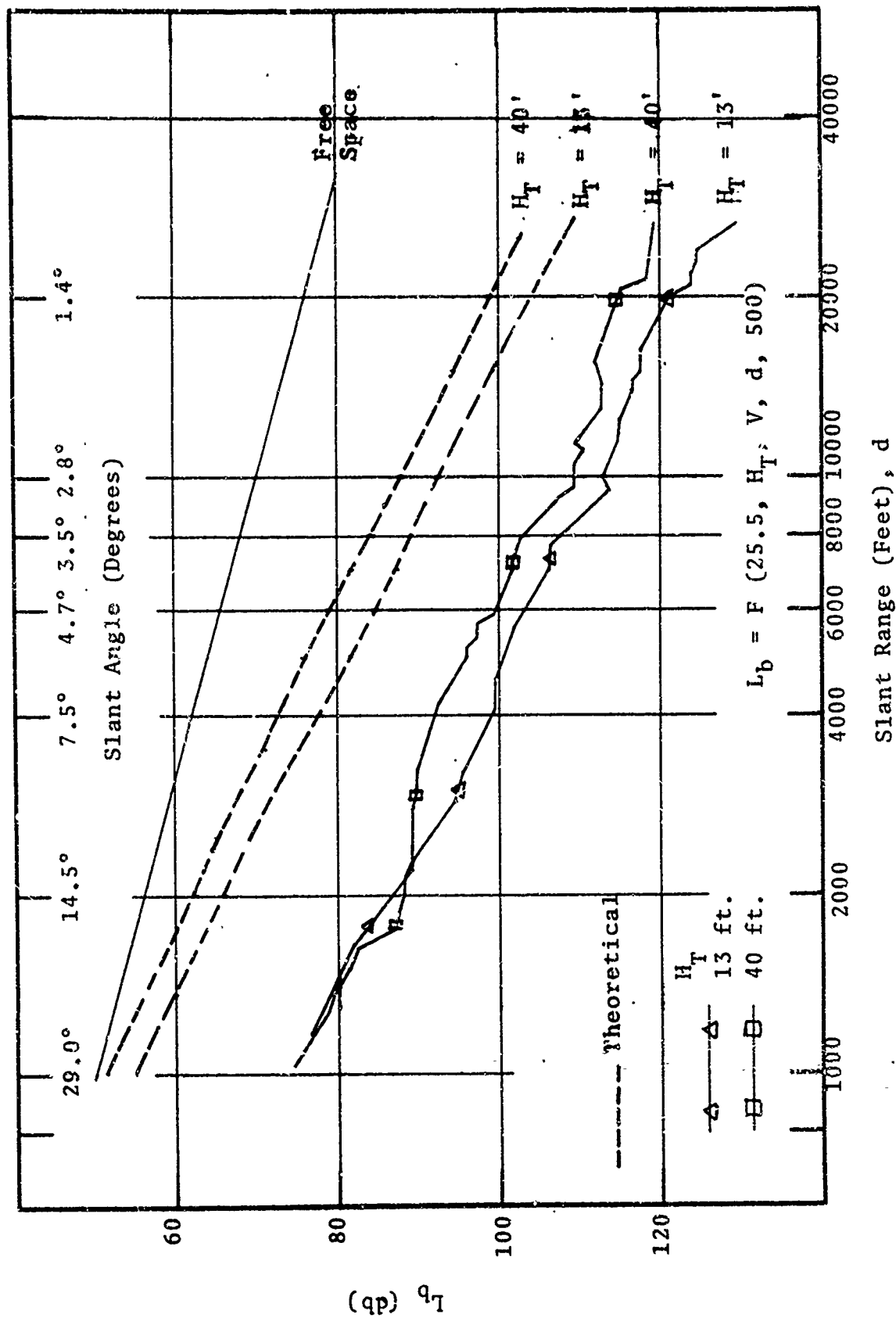


Figure 4.3.10 Comparison of L_b vs. Distance Along 325° Radial For Various Transmitting Antenna Heights

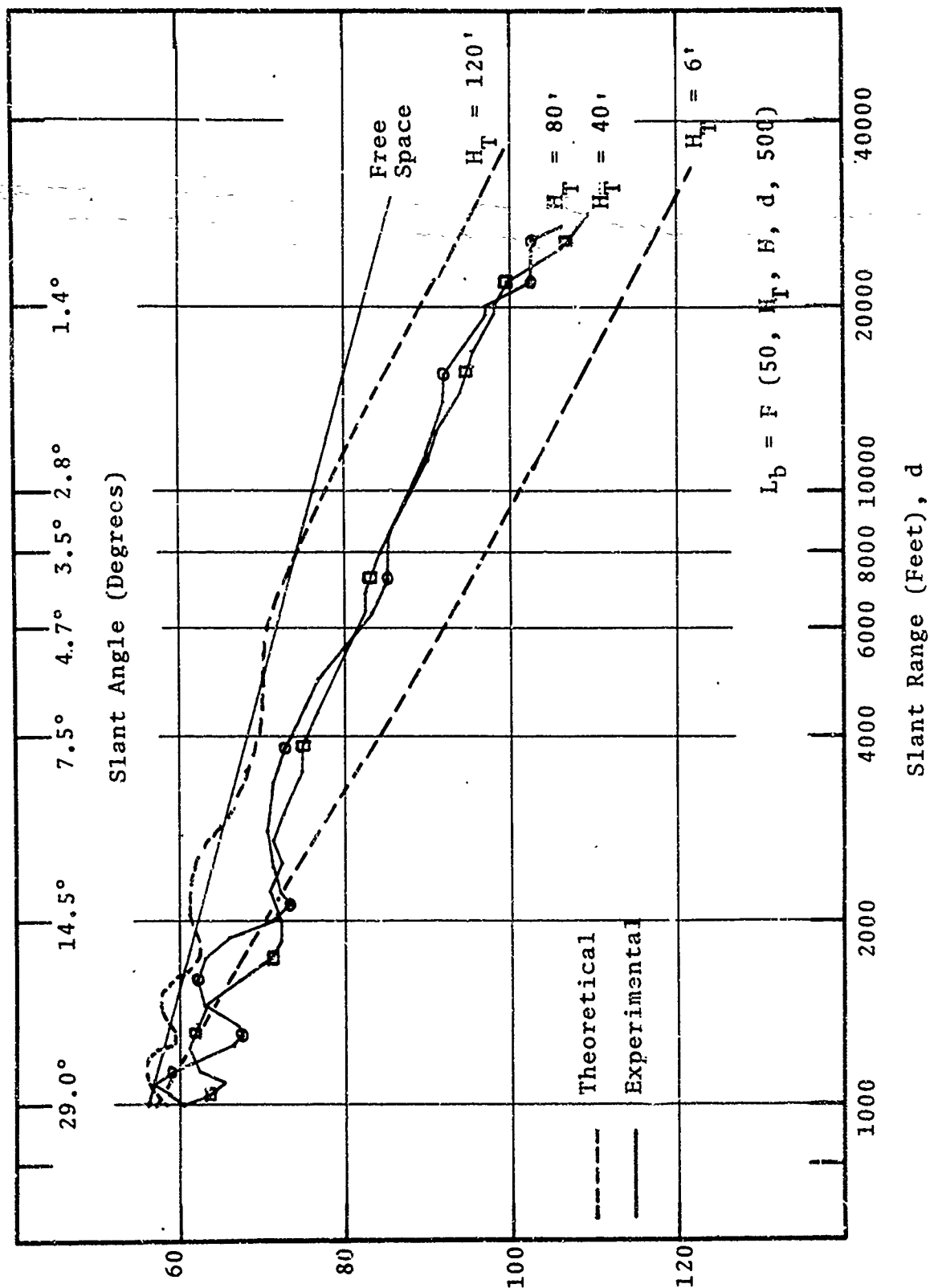


Figure 4.3.11 Comparison of L_b vs. Distance Along 325° Radial For Various Transmitting Antenna Heights

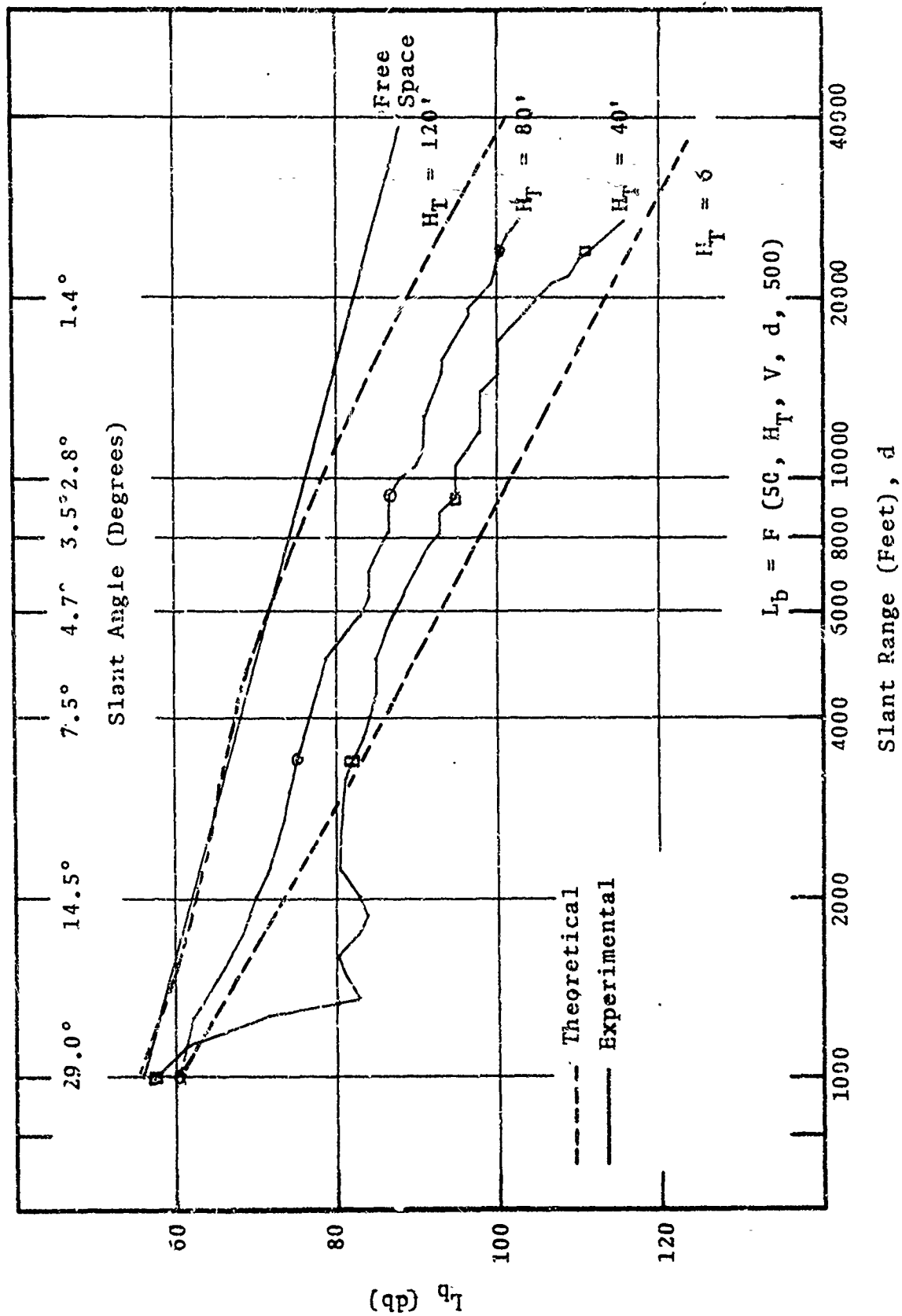


Figure 4.3.12 Comparison Of L_b Vs. Distance Along 325° Radial For Various Transmitting Antenna Heights

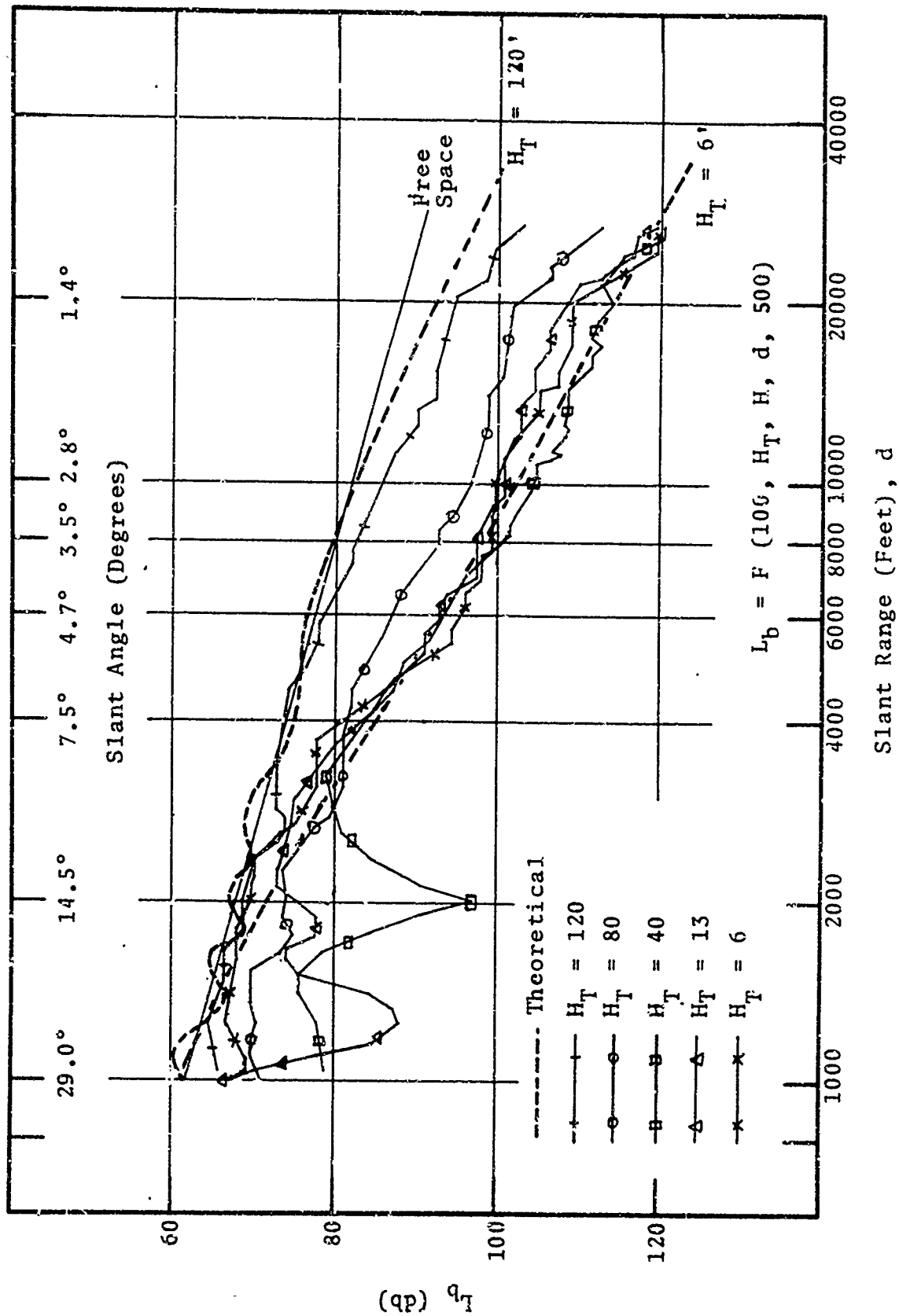


Figure 4.3.13 Comparison of L_b Vs. Distance Along 325° Radial For Various Transmitting Antenna Heights

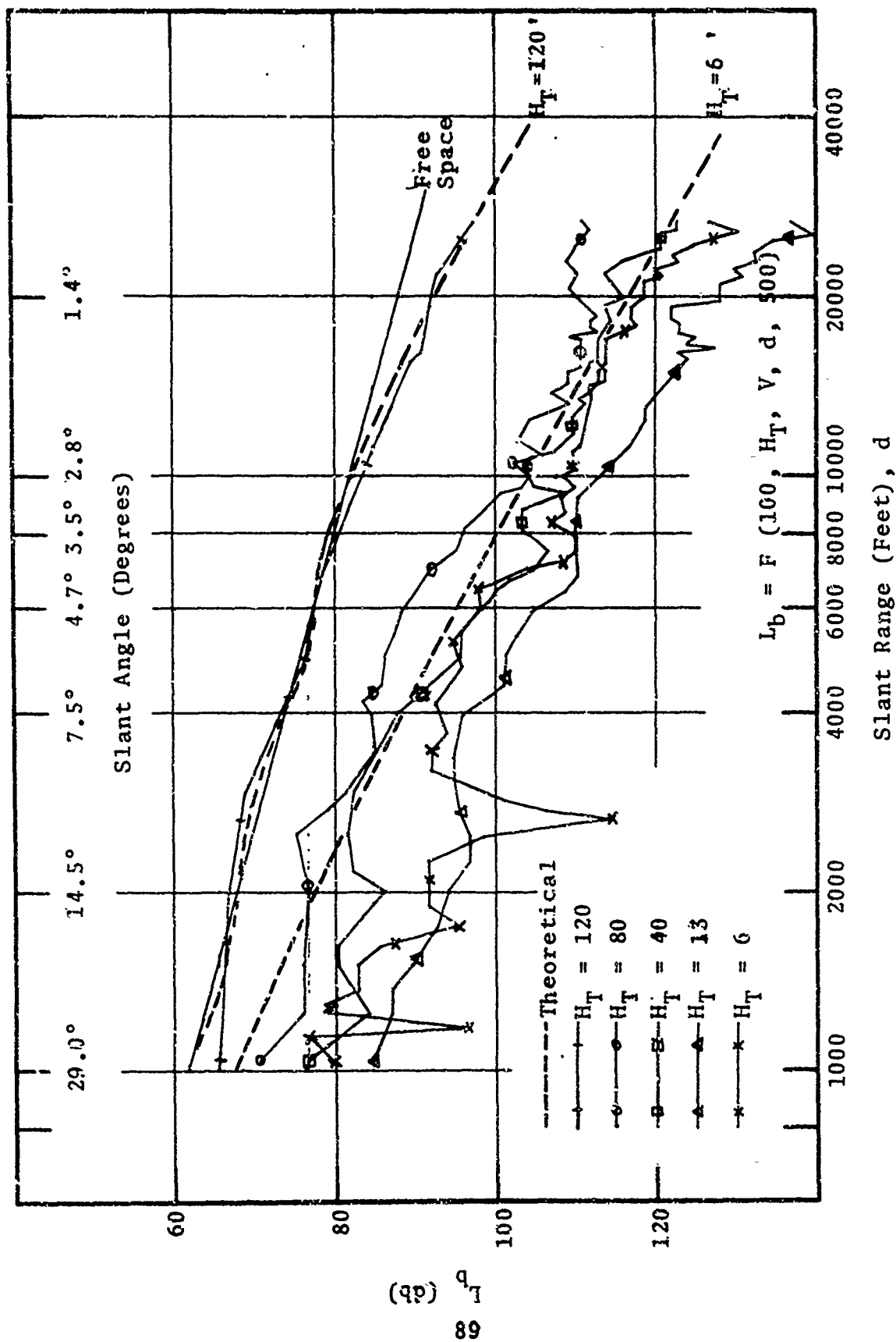


Figure 4.3.14 Comparison of L_p Vs. Distance Along 325° Radial For Various Transmitting Antenna Heights

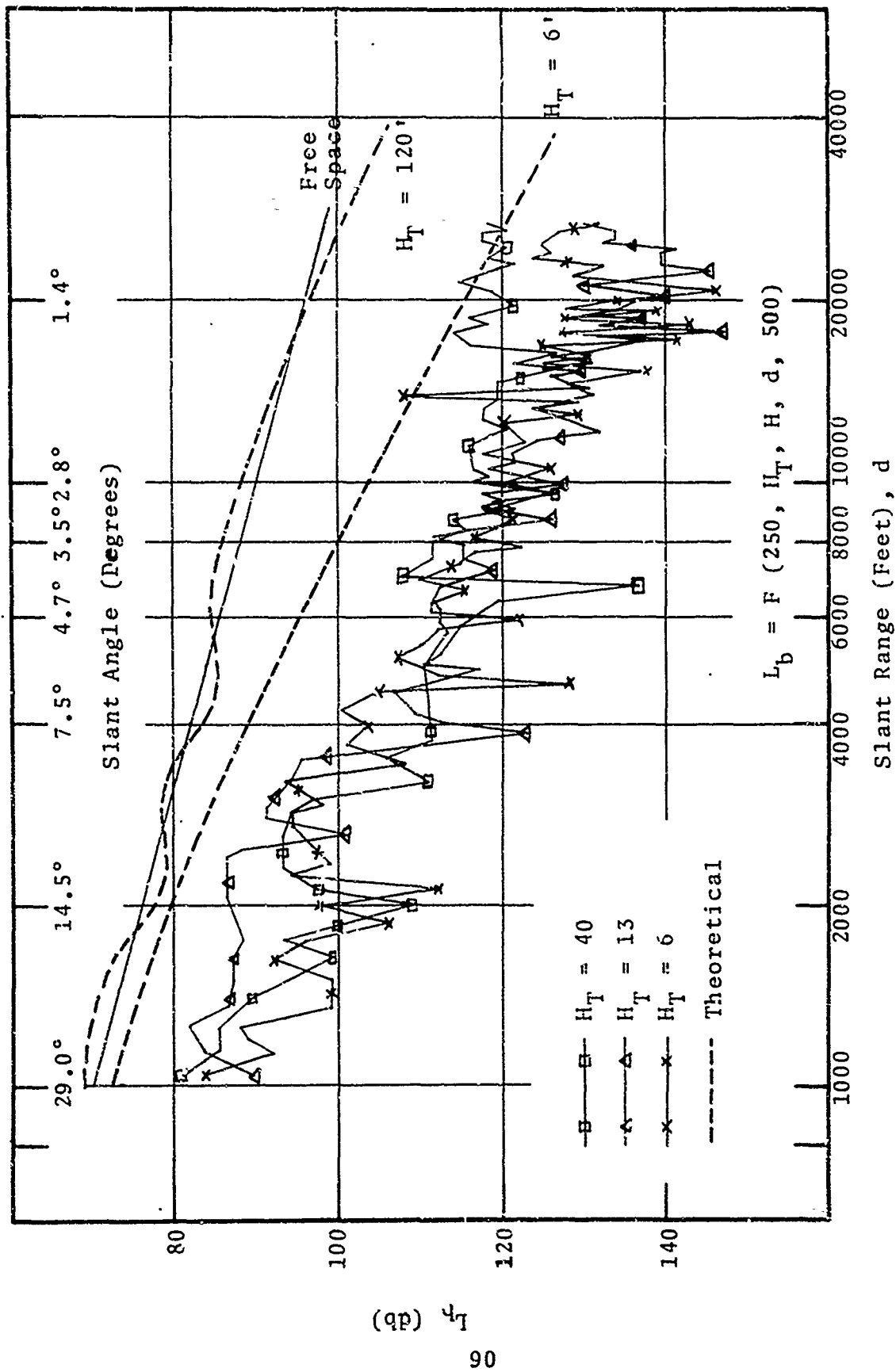


Figure 4.3.15 Comparison of L_b Vs. Distance Along 325° Radial For Various Transmitting Antenna Heights

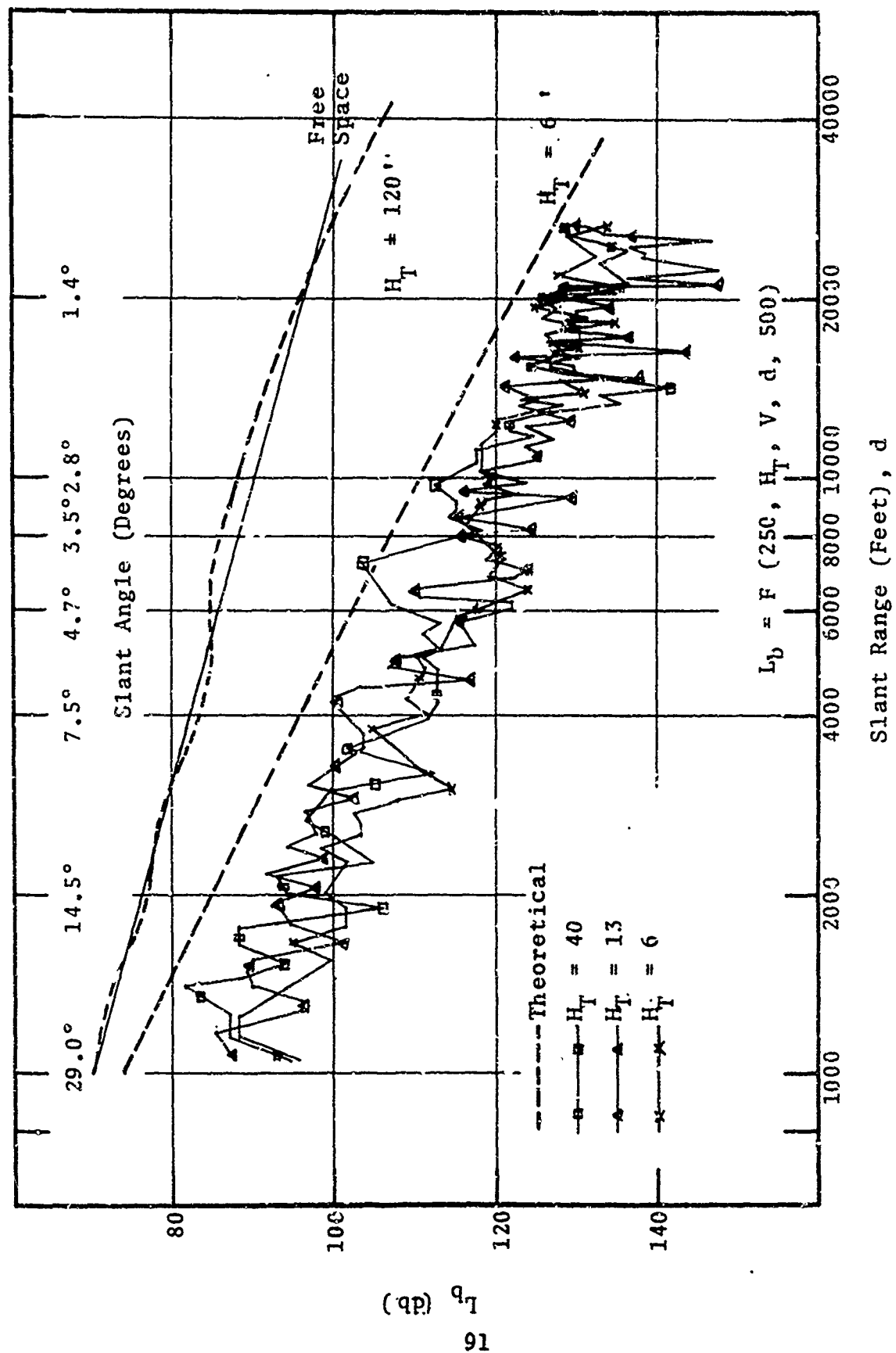


Figure 4.3.16 Comparison Of L_b Vs. Distance Along 325° Radial For Various Transmitting Antenna Heights

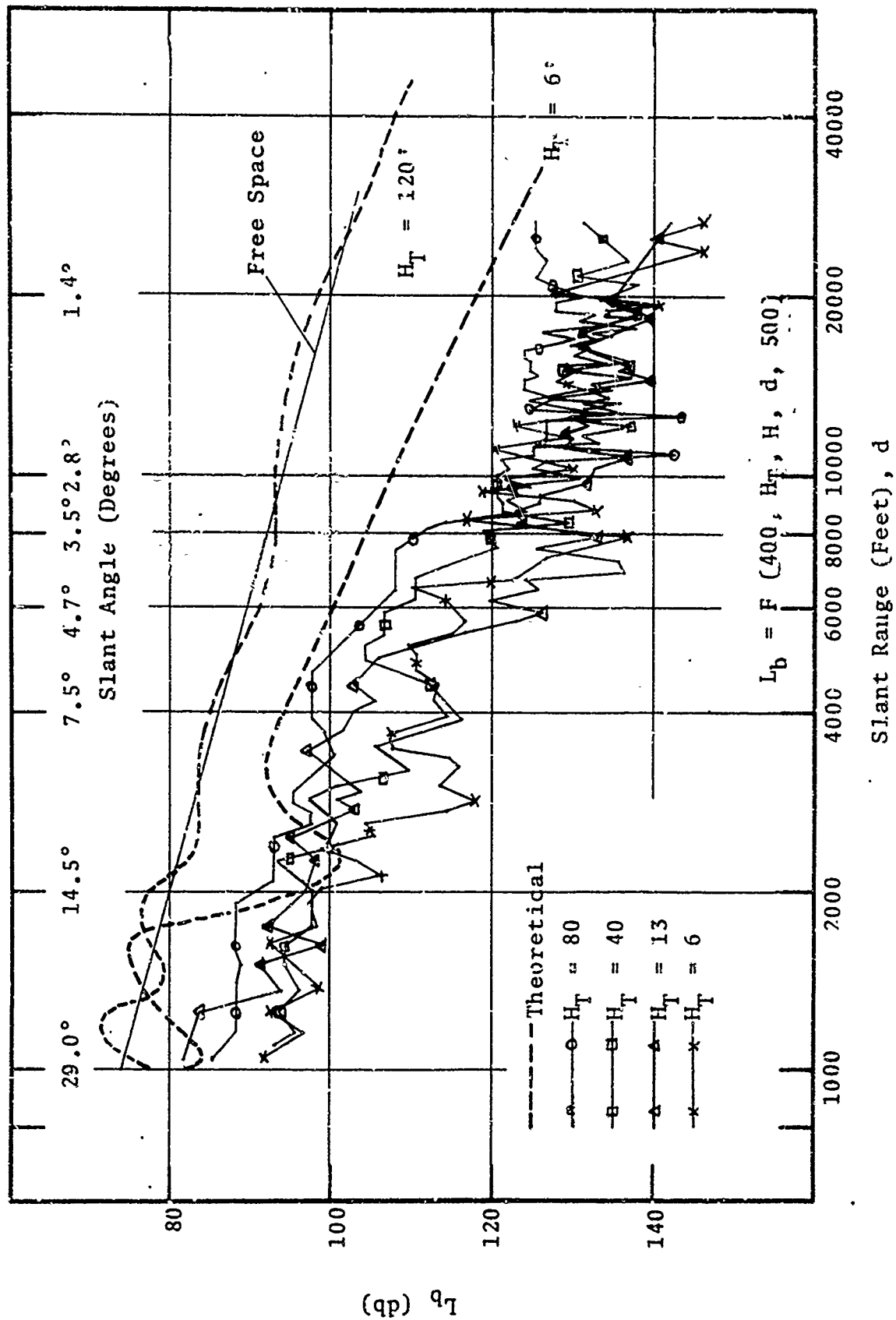


Figure 4.3.17 Comparison Of L_b Vs. Distance Along 325° Radial For Various Transmitting Antenna Heights

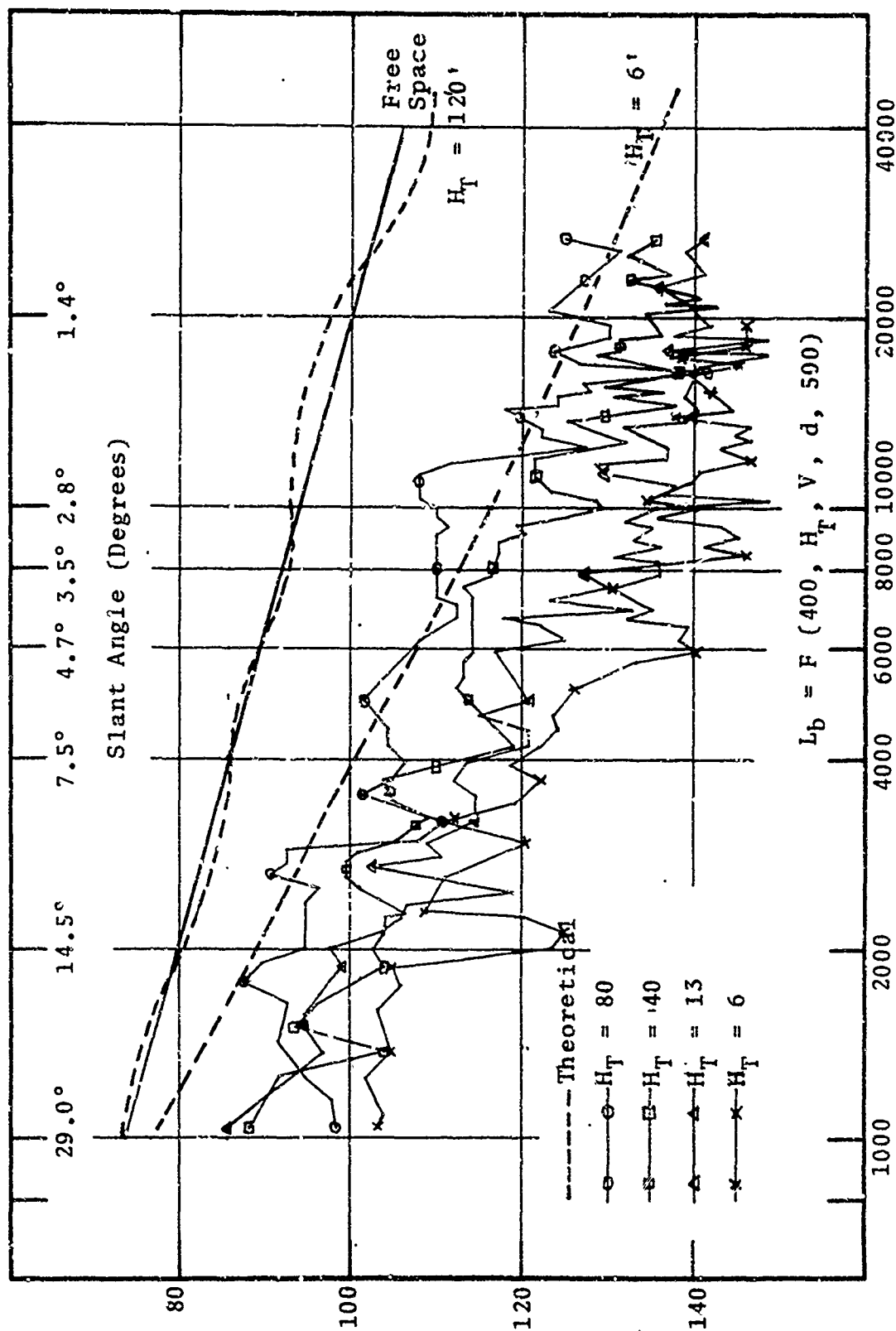


Figure 4.3.18 Comparison Of L_b Vs. Distance Along 325° Radial For Various Transmitting Antenna Heights

average loss for frequencies of 25 to 400 MHz, extension to a scatter model is desirable to account for the variability.

4.4 Conclusions

The basic transmission loss for jungle-to-air propagation paths at frequencies of 25 to 400 MHz differs by as much as 10 - 15 db or so for different azimuthal directions of propagation. This difference is not consistent with frequency or polarization over the different paths, which suggests the difference in loss over the different paths may be due to multipaths originating from the vicinity of the transmitter (ground terminal) rather than gross differences in the homogeneity of the jungle when viewed as a uniform conducting slab.

The basic transmission loss increases with range and exhibits a significant variability which increases with increasing frequency.

The basic transmission loss decreases with increasing ground terminal antenna height and exhibits considerable variability which increases with frequency. This variability also tends to decrease with increasing ground terminal antenna height.

The basic transmission loss is generally less for horizontal than vertical polarization with this difference decreasing as frequency and/or ground terminal antenna height increases.

The theoretical basic transmission, based on the uniform conducting slab model for the forest in Area II, is in fair agreement with the average experimental loss. The agreement could be improved by employing electrical parameters and heights for the slab model which vary with frequency. Extension of the slab model to include scattering, however, appears to be required to adequately explain the data.

5. MIXED PATH PROPAGATION

Most of the theoretical and experimental work accomplished and reported on this program has thus far been concerned with regarding the jungle environment as a uniform slab over the path of propagation. This approach has been necessary in order to systematically define the quantitative influence of the vegetation upon radio propagation, and the attainment of an analytical model that generally explains the experimentally observed propagation behavior. The state has been reached where the smoothed values of the experimental data and the theoretical model are in fairly good agreement, provided suitable empirically derived effective electrical constants of the jungle vegetation are used.

It has been recognized that practical communication in a jungle environment more often than not involves propagation over paths consisting of both vegetative and cleared areas. In this report such paths are referred to as "mixed paths." Some work has been done by Head [1960] on mixed paths at UHF, but the extension of his results to practical mixed paths in jungle environments is not obvious. Thus, to provide a data base for the development of a model for mixed path conditions, a special series of propagation measurements were conducted in Area II, the environment of which has been previously discussed. Data was obtained for a variety of mixed path configurations. The experimental results from this series of measurements have been reported in Data Bulletins Numbers 5, 6 and 7. This data is much too voluminous for inclusion in this report, but this section will present and discuss those data which appear to be revealing of the significant features of propagation over such mixed paths. Also, a

theoretical treatment of propagation over the mixed clearing-vegetation or vegetation-vegetation mixed path is presented and compared with experimental results.

5.1 Experimental Procedures

Propagation measurements were made over the mixed paths of foliage-clearing-foliage (configuration A) and clearing-foliage-clearing (configuration B). There were several subconfigurations to configurations A and B which were obtained by reducing the amount of foliage over each path in successive steps. In the A configuration, A0 is an all-foliage path along a radial from the transmitter, A1 is along the same path with a block of foliage removed, and in A2 another block of foliage is removed to essentially double the size of the path through the intervening clearing. In the B configuration, B0 is a path along a radial from the transmitter extending from clearing through foliage to clearing. B1 is the same as B0 except the underbrush is cut from the last one-quarter of the foliage path, B2 is the same with the remaining foliage cut along the last one-quarter of the foliage path, B3 is the path with the underbrush cut from the next one-quarter of the path, etc.

Figures 5.1.1 and 5.1.2 are sketches of the foliage-clearing configurations A2 and B0, respectively, showing the terrain profile over the paths, the transmitter locations for all measurements and receiver locations used in the height-gain measurements for all configurations. Figures 5.1.3 and 5.1.4 are sketches illustrating the specific foliage-clearing paths and the transmitter antenna location for all measurements, and receiver antenna locations for height-gain measurements for A and B configurations, respectively. These figures are helpful in interpreting the computer print-outs in this section.

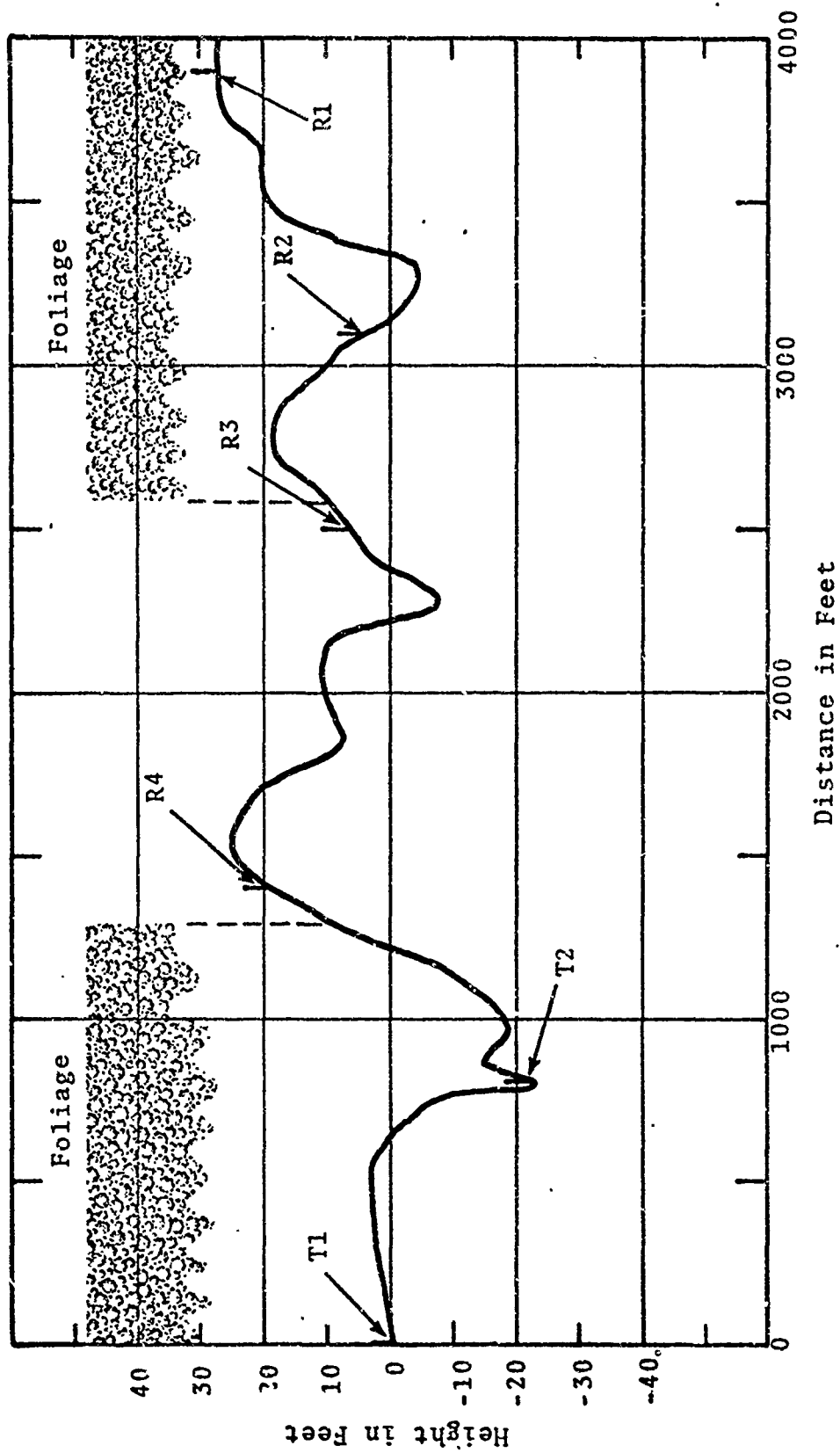


Figure 5.1.1 Terrain Profile for 'L' Radial - Configuration A

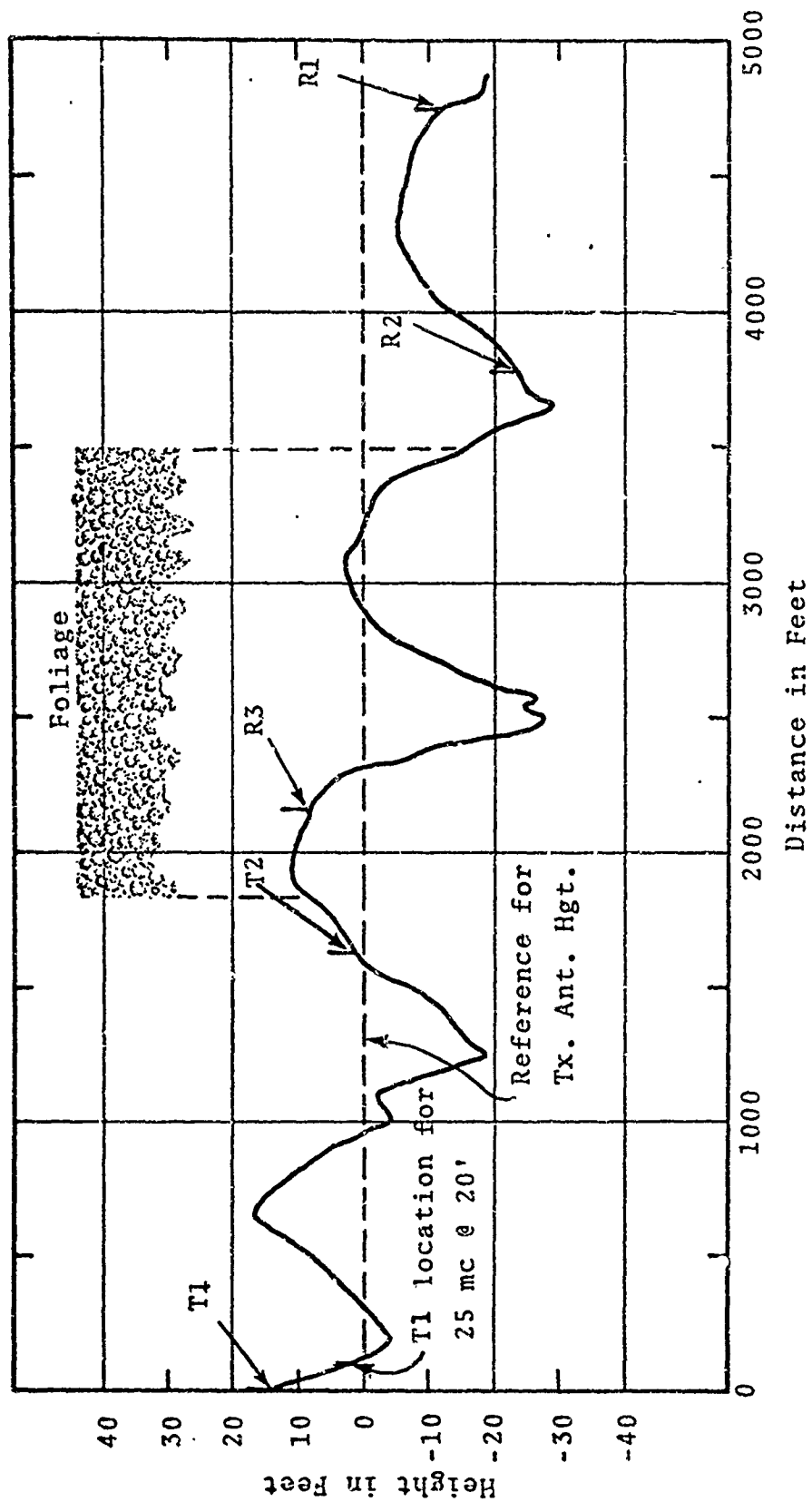


Figure 5.1.2 Terrain Profile for 'K' Radial - Configuration B

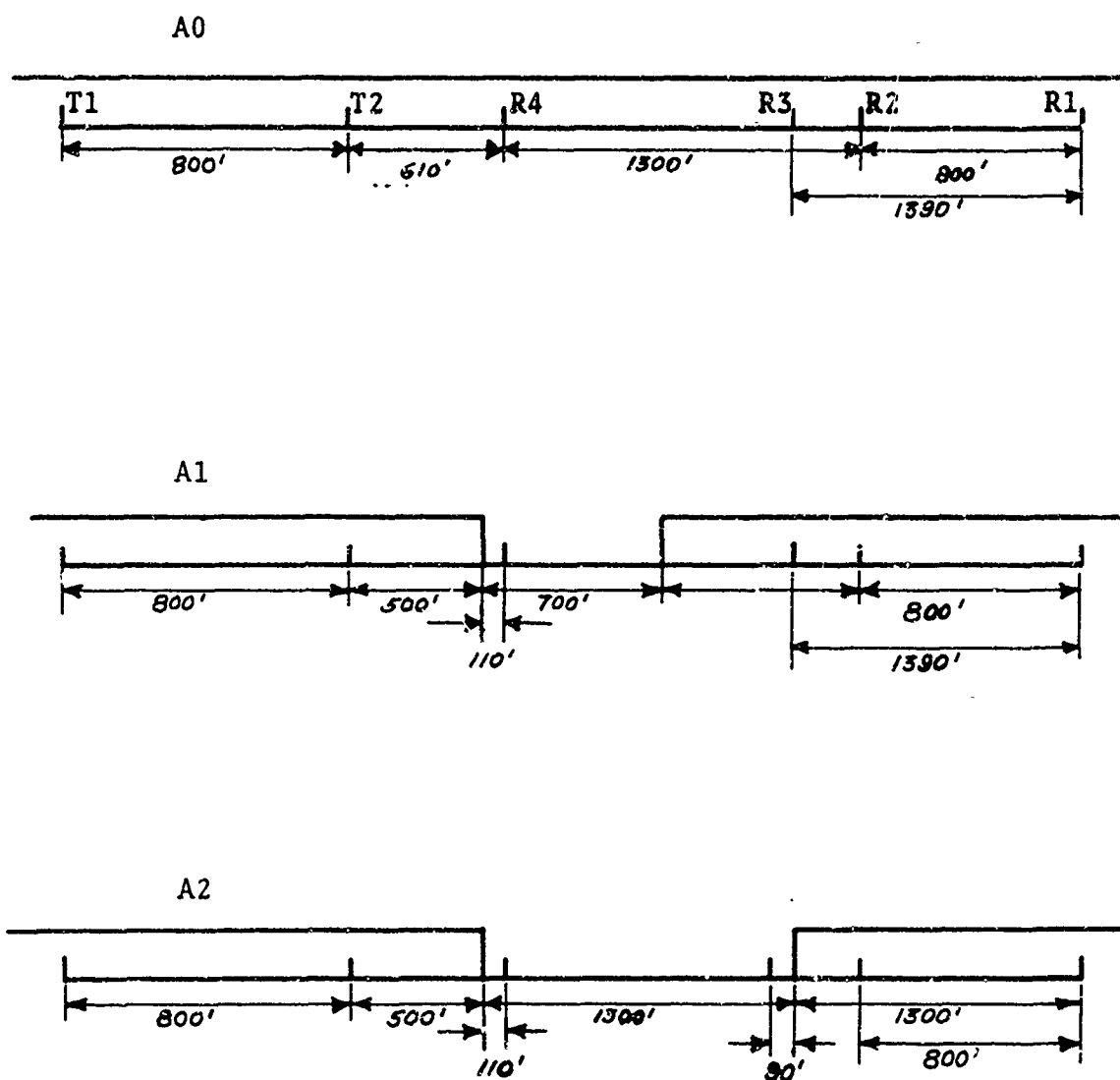


Figure 5.1.3 Nomenclature for Configuration A
Mixed Path Height-Gain Measurements

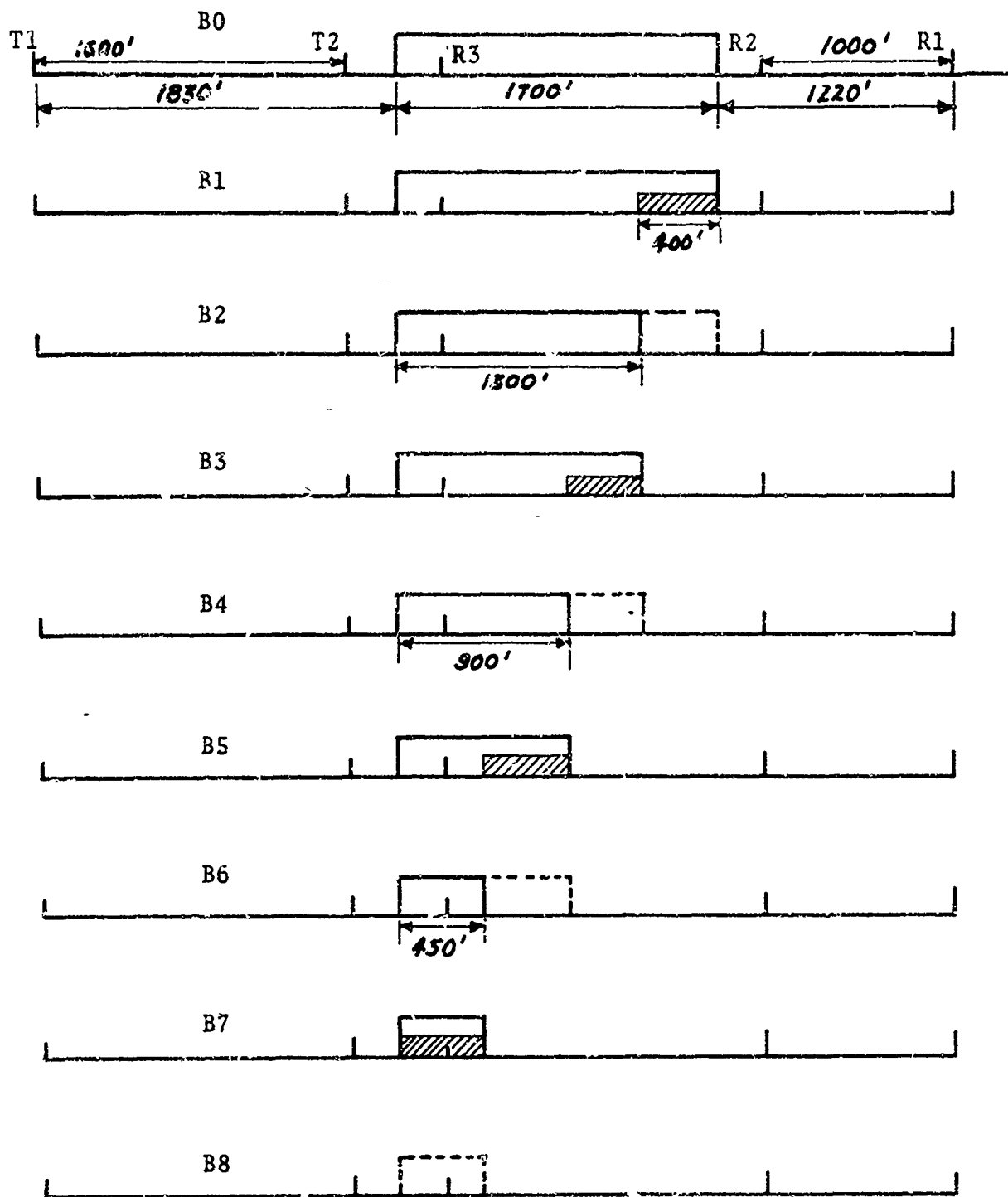


Figure 5.1.4 Nomenclature for Configuration B
Mixed Path Height-Gain Measurements

In general, two types of measurements were made for each configuration. In one, called "height-gain measurements," the transmitter and receiver were separated by a fixed distance. The transmitter was stationary, and the receiver antenna height varied between 8 and 80 feet. The maximum and minimum field strength, in db relative to 1 μ volt/m, over each 5-7 foot height interval was recorded as the receive antenna height was changed.

In the other measurements, called "walking measurements," the transmitter antenna was stationary and the receive antenna was moved in range, at the fixed height of 6 feet, along a radial from the transmitter. The maximum and minimum receive signal, in db relative to 1 μ volt/m, over an area of \approx 10-foot diameter, was recorded at each 50 or 100-foot range interval along the radial. The measurements were taken at 50-foot intervals near the foliage-clearing interfaces and at 100-foot intervals otherwise.

Several combinations of frequency of 25, 50, 100 and 250 MHz, vertical and horizontal polarization, transmitter antenna heights and locations, and receiver heights were employed. Figures 5.1.5 and 5.1.6 are tree diagrams showing these for the height-gain and walking measurements, respectively. The figure numbers in Figure 5.1.5 and 5.1.6 reference the graphic data presented in the next section.

The antennas were half-wave dipoles in all cases except the receiving antenna at 25 MHz, which was a small loop. The antennas were oriented with their maximum free space gain along the line-of-sight path between transmitter and receiver. The transmitting and receiving equipment and calibration procedures have been discussed previously [Jansky & Bailey, 1966].

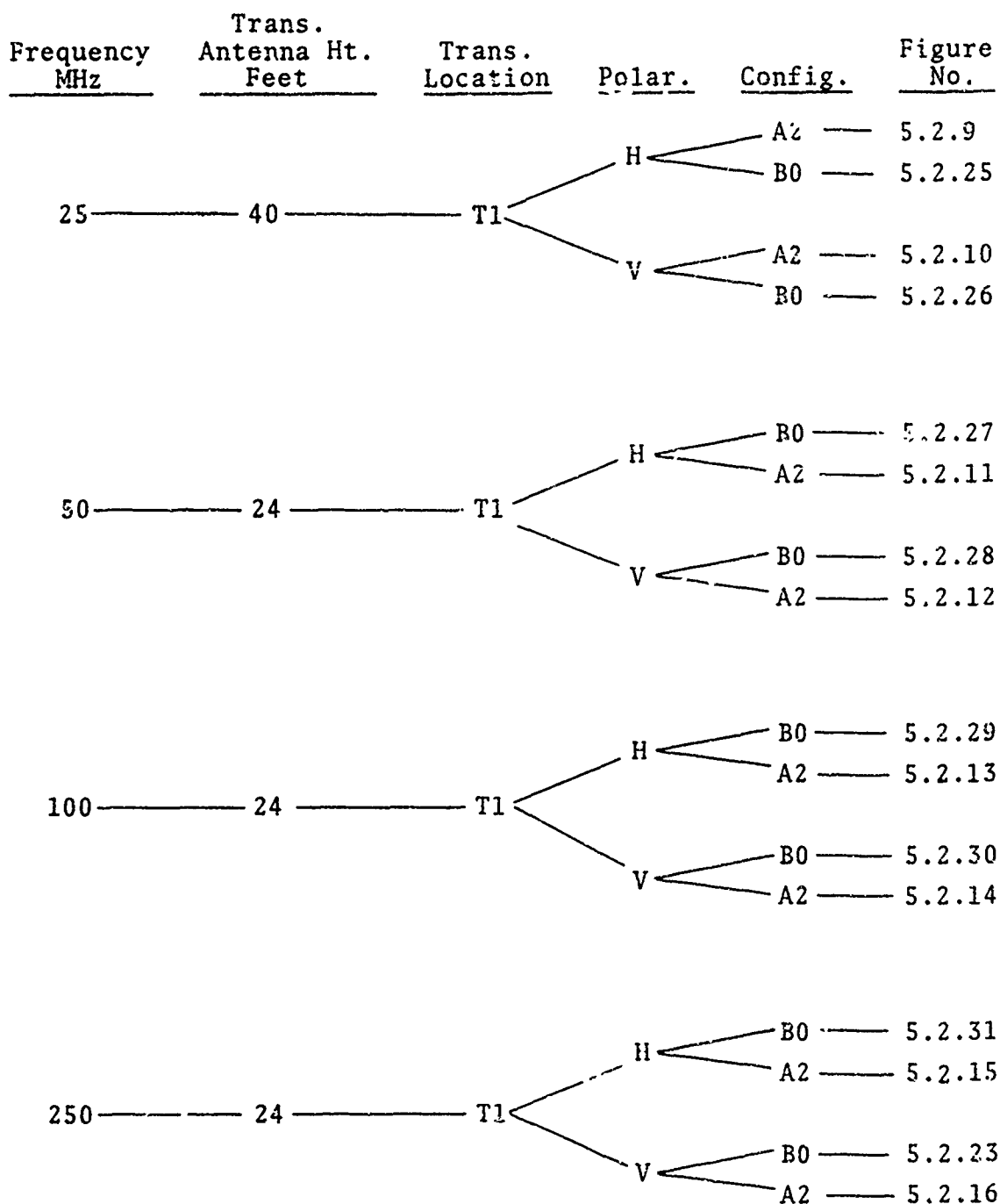


Figure 5.1.5 Tree Diagram of Mixed Path Height-Gain Graphs

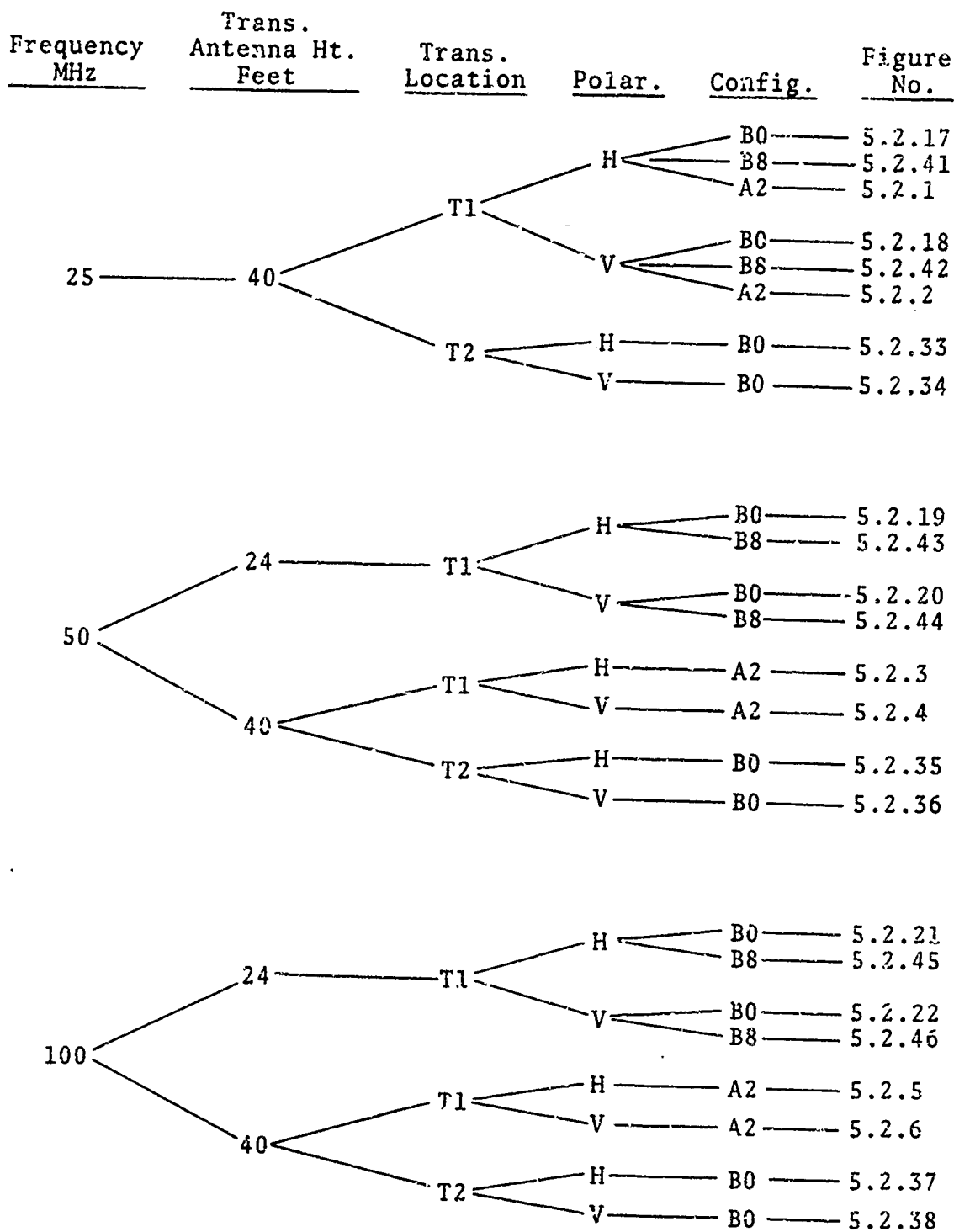


Figure 5.1.6 Tree Diagram of Mixed Path Data,
Horizontal Distance Abscissa

<u>Frequency</u> <u>MHz</u>	<u>Trans.</u> <u>Antenna Ht.</u> <u>Feet</u>	<u>Trans.</u> <u>Location</u>	<u>Polar.</u>	<u>Config.</u>	<u>Figure</u> <u>No.</u>
250	24	T1	H	B0	5.2.23
				B8	5.2.47
			V	B0	5.2.24
				B8	5.2.48
	40	T1	H	A2	5.2.7
			V	A2	5.2.8
		T2	H	B0	5.2.39
			V	B0	5.2.40

Figure 5.1.6 (continued)

For those readers who have received Data Bulletin Number 7, it should be noted that the height of the transmitting antenna for configuration B was referenced to a level base line, as shown in Figure 5.1.2. In the graphs in this report (i.e., Figures 5.2.9 to 5.2.32) the transmitting and receiving antenna heights are referenced to the ground level at the base of the antenna.

5.2 Data Analysis and Discussion

With the aid of a computer, the large number of field strength measurements for configurations A and B were reduced to basic transmission loss L_b for isotropic antennas. The resultant L_b includes any losses due to the antennas being near ground or foliage, caused by antenna impedance changes, as well as the loss over the transmission path. The antenna impedance changes due to foliage and ground proximity are, however, expected to be negligible at the frequencies and antenna heights employed in these measurements [Dence and Tamir, 1969].

Figures 5.2.1 to 5.2.8 show the basic transmission loss as a function of distance (walking data), with the terrain profile shown, for the transmitter at T1 for the A2 configuration. Figures 5.2.9 to 5.2.16 show the basic transmission loss as a function of receiver antenna height (height-gain) for the transmitter at T1 in the A2 configuration. Figures 5.2.17 to 5.2.24 show the basic transmission loss as a function of distance, with the terrain profile shown, for the transmitter at T1 in the B0 configuration. Figures 5.2.25 to 5.2.32 show the basic transmission loss as a function of receiver antenna heights for the transmitter at T1 in the B0 configuration. Figures 5.2.33 to 5.2.40 show the basic transmission loss as a function of distance, with the terrain profile shown, for the transmitter at T2 in the B0 configuration. Figures 5.2.41 to

MIXED PATH BASIC TRANSMISSION LOSS CALCULATING DATA CONFIGURATION A-2, TRANSMITTER T-1

FREQ = 2500000 Hz, HPL = 9000000 Hz

DISTANCE	MINLOS(DB)	MAXLOS(DB)	DISP(F)	MINLOS(DB)	MAXLOS(DB)
750.0	80000	80000	800.0	74.0	77.0
850.0	77.0	79.0	900.0	87.0	89.0
950.0	83.0	85.0	1000.0	82.0	84.0
1050.0	86.0	88.0	1100.0	83.0	85.0
1150.0	78.0	80.0	1200.0	78.0	80.0
1250.0	79.0	81.0	1300.0	79.0	81.0
1350.0	81.0	83.0	1400.0	81.0	83.0
1450.0	81.0	83.0	1500.0	81.0	83.0
1550.0	85.0	87.0	1600.0	82.0	84.0
1650.0	85.0	87.0	1700.0	82.0	84.0
1750.0	84.0	86.0	1800.0	85.0	87.0
1850.0	84.0	86.0	1900.0	84.0	86.0
1950.0	87.0	89.0	2000.0	85.0	87.0
2050.0	87.0	89.0	2100.0	90.0	91.0
2150.0	90.0	91.0	2200.0	90.0	91.0
2250.0	93.0	94.0	2300.0	91.0	92.0
2350.0	93.0	94.0	2400.0	93.0	94.0
2450.0	96.0	97.0	2500.0	90.0	91.0
2550.0	96.0	97.0	2600.0	90.0	91.0
2650.0	99.0	100.0	2700.0	93.0	94.0
2750.0	99.0	100.0	2800.0	96.0	97.0
2850.0	102.0	103.0	2900.0	96.0	97.0
2950.0	102.0	103.0	3000.0	102.0	103.0
3050.0	102.0	103.0	3100.0	98.0	99.0
3150.0	102.0	103.0	3200.0	97.0	98.0
3250.0	102.0	103.0	3300.0	97.0	98.0
3350.0	102.0	103.0	3400.0	97.0	98.0
3450.0	102.0	103.0	3500.0	97.0	98.0
3550.0	102.0	103.0	3600.0	97.0	98.0
3650.0	102.0	103.0	3700.0	97.0	98.0
3750.0	102.0	103.0	3800.0	97.0	98.0
3850.0	102.0	103.0	3900.0	97.0	98.0
3950.0	102.0	103.0	4000.0	97.0	98.0

Figure S.2.1 (continued)

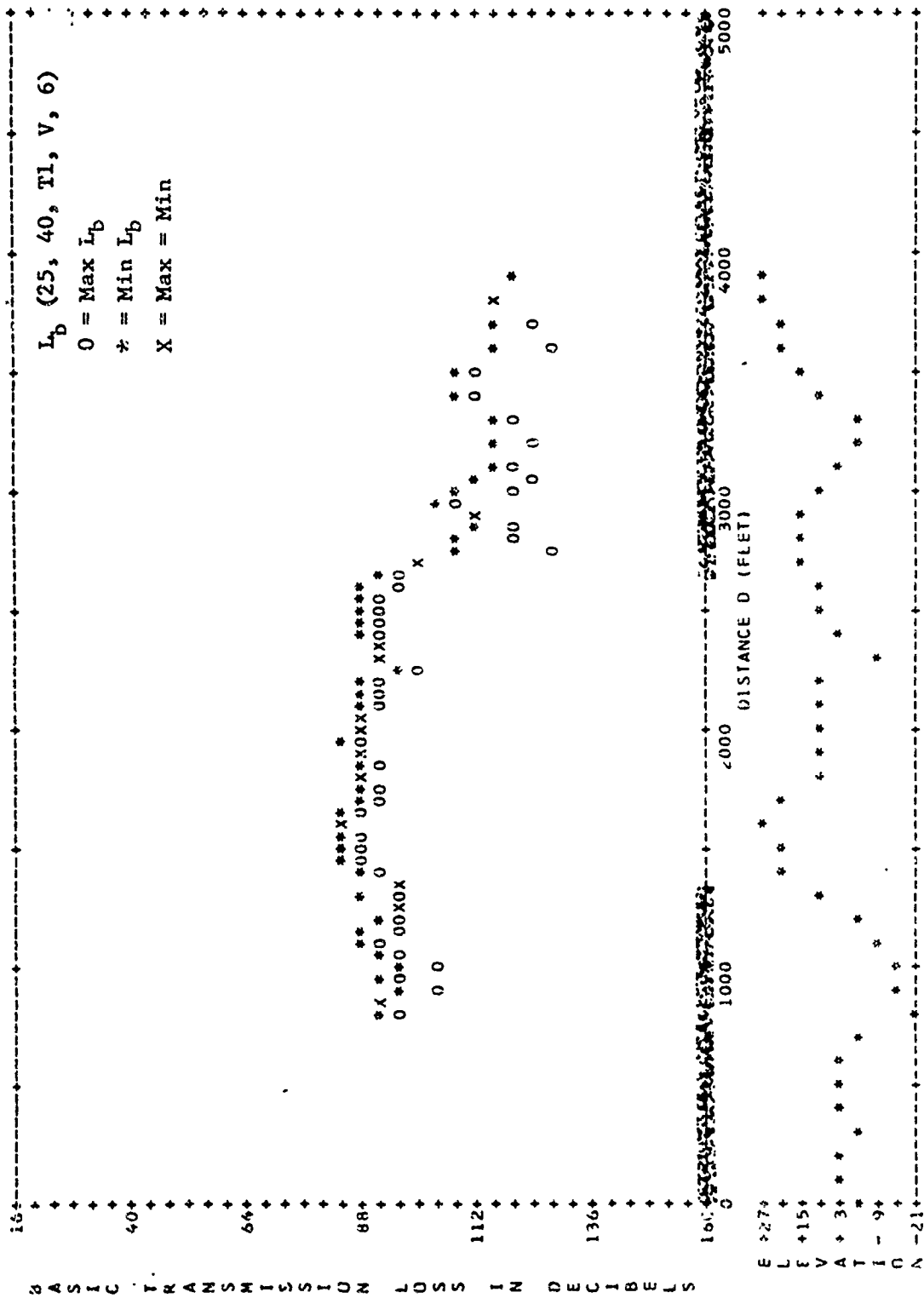


Figure 5.2.2. Basic Transmission Loss and Terrain Elevation vs Distance for Configuration A-2.

MIXED PATH BASIC TRANSMISSION LOSS
WALKING DATA CONFIGURATION W-2, TRANSMITTER T-1

FFCJ = 250HZ, HT = 40FT, PUL = V

DIST(FT)	MINL5(DB)	MAXLB(DB)	DTCT(FT)	MINLR(DB)	MAXLB(DB)
750.0	****	****	800.0	94.0	98.0
850.0	91.0	94.0	900.0	97.0	105.0
950.0	92.0	97.0	1000.0	96.0	103.0
1050.0	92.0	97.0	1100.0	89.0	93.0
1150.0	89.0	95.0	1200.0	94.0	96.0
1250.0	95.0	98.0	1300.0	90.0	95.0
1350.0	96.0	97.0	1400.0	90.0	93.0
1450.0	85.0	87.0	1500.0	83.0	87.0
1550.0	84.0	87.0	1600.0	85.0	86.0
1650.0	86.0	88.0	1700.0	88.0	91.0
1750.0	88.0	91.0	1800.0	88.0	90.0
1850.0	89.0	91.0	1900.0	88.0	90.0
1950.0	86.0	90.0	2000.0	87.0	90.0
2050.0	88.0	89.0	2100.0	88.0	92.0
2150.0	89.0	91.0	2200.0	90.0	94.0
2250.0	95.0	99.0	2300.0	91.0	93.0
2350.0	93.0	94.0	2400.0	90.0	92.0
2450.0	89.0	93.0	2500.0	90.0	91.0
2550.0	94.0	98.0	2600.0	85.0	95.0
2650.0	94.0	98.0	2700.0	100.0	102.0
2750.0	110.0	128.0	2800.0	109.0	119.0
2850.0	111.0	119.0	2900.0	113.0	114.0
2950.0	105.0	110.0	3000.0	110.0	121.0
3050.0	113.0	123.0	3100.0	115.0	122.0
3150.0	****	****	3200.0	117.0	123.0
3250.0	****	****	3300.0	115.0	119.0
3350.0	****	****	3400.0	110.0	114.0
3450.0	****	****	3500.0	107.0	111.0
3550.0	****	****	3600.0	114.0	123.0
3650.0	****	****	3700.0	118.0	126.0
3750.0	****	****	3800.0	116.0	117.0
3850.0	****	****	3900.0	120.0	****

Figure 5.2.2 (continued)

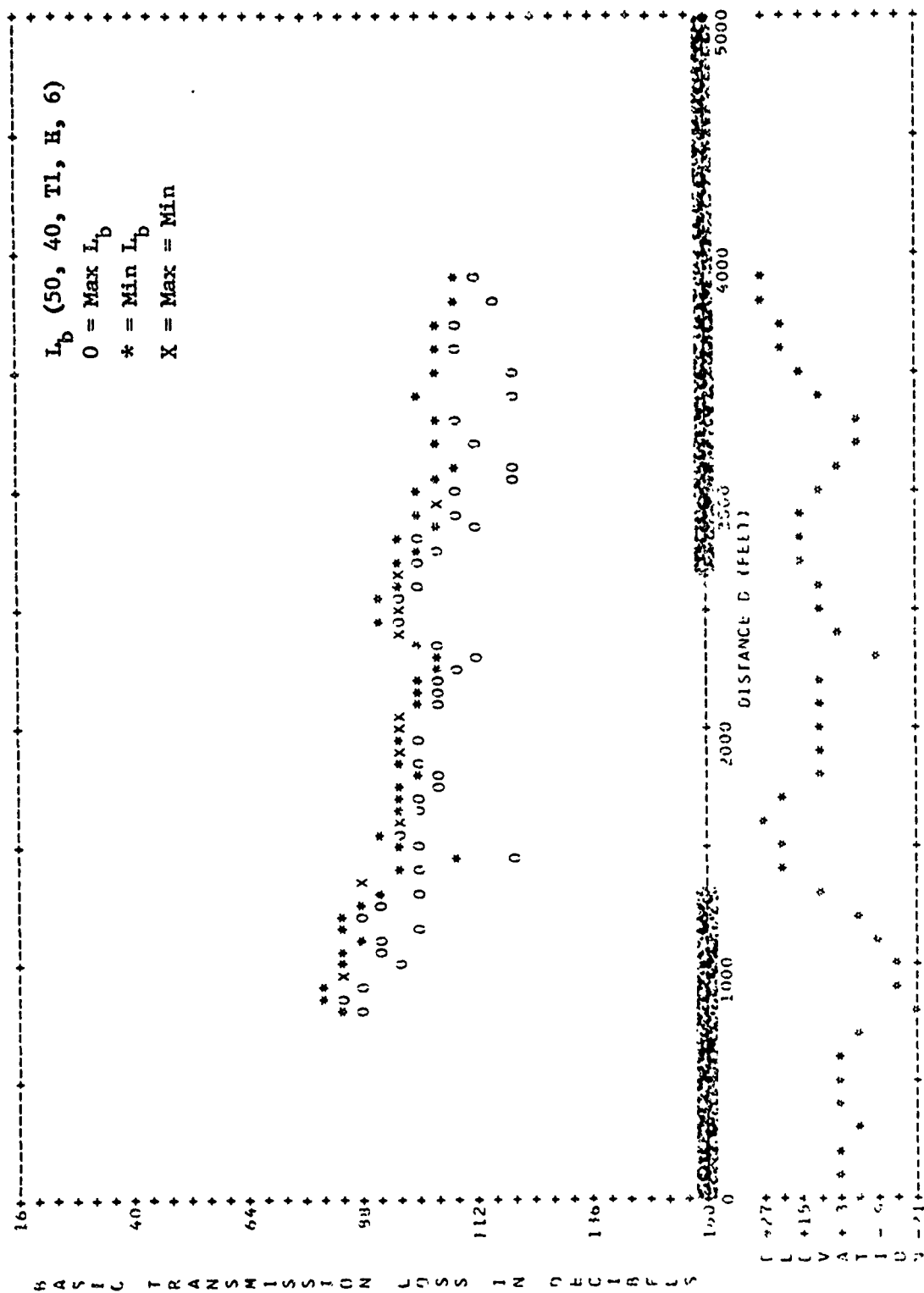


Figure 5.2.3. Basic Transmission Loss and Terrain Elevation vs Distance for Configuration A-2.

MIXED PATH BASIC TRANSMISSION LOSS
WALKING DATA CONFIGURATION, A-2, TRANSMITTER 1-1

FREQ. = 50MHz, fref. = 40ft., PUL. = H

DIST (FT)	MIN LOSS (DB)	MAX LOSS (DB)	DIST (FT)	MIN LOSS (DB)	MAX LOSS (DB)
750.0	80.0	85.5	800.0	83.5	86.5
850.0	83.5	89.0	900.0	82.5	87.5
950.0	85.5	91.0	1000.0	84.5	89.5
1050.0	87.5	93.0	1100.0	87.5	91.5
1150.0	89.0	94.5	1200.0	93.5	87.5
1250.0	91.0	96.5	1300.0	96.5	100.5
1350.0	92.5	98.0	1400.0	97.5	98.5
1450.0	94.0	99.5	1500.0	97.5	98.5
1550.0	95.5	101.0	1600.0	97.5	95.5
1650.0	97.0	102.5	1700.0	95.5	100.5
1750.0	98.5	104.0	1800.0	95.5	102.5
1850.0	100.0	105.5	1900.0	94.5	97.5
1950.0	101.5	107.0	2000.0	94.5	95.5
2050.0	103.0	108.5	2100.0	94.5	93.5
2150.0	104.5	109.5	2200.0	94.5	103.5
2250.0	106.0	111.0	2300.0	94.5	104.5
2350.0	107.5	112.5	2400.0	94.5	104.5
2450.0	109.0	114.0	2500.0	94.5	97.5
2550.0	110.5	115.5	2600.0	94.5	95.5
2650.0	112.0	117.0	2700.0	94.5	99.5
2750.0	113.5	118.5	2800.0	94.5	101.5
2850.0	115.0	120.0	2900.0	94.5	100.5
2950.0	116.5	121.5	3000.0	94.5	108.5
3050.0	118.0	123.0	3100.0	94.5	109.5
3150.0	119.5	124.5	3200.0	94.5	115.5
3250.0	121.0	126.0	3300.0	94.5	115.5
3350.0	122.5	127.5	3400.0	94.5	106.5
3450.0	124.0	129.0	3500.0	94.5	121.5
3550.0	125.5	130.5	3600.0	94.5	120.5
3650.0	127.0	132.0	3700.0	94.5	106.5
3750.0	128.5	133.5	3800.0	94.5	109.5
3850.0	130.0	135.0	3900.0	94.5	117.5
3950.0	131.5	136.5	4000.0	94.5	111.5

Figure 5.2.3 (continued)

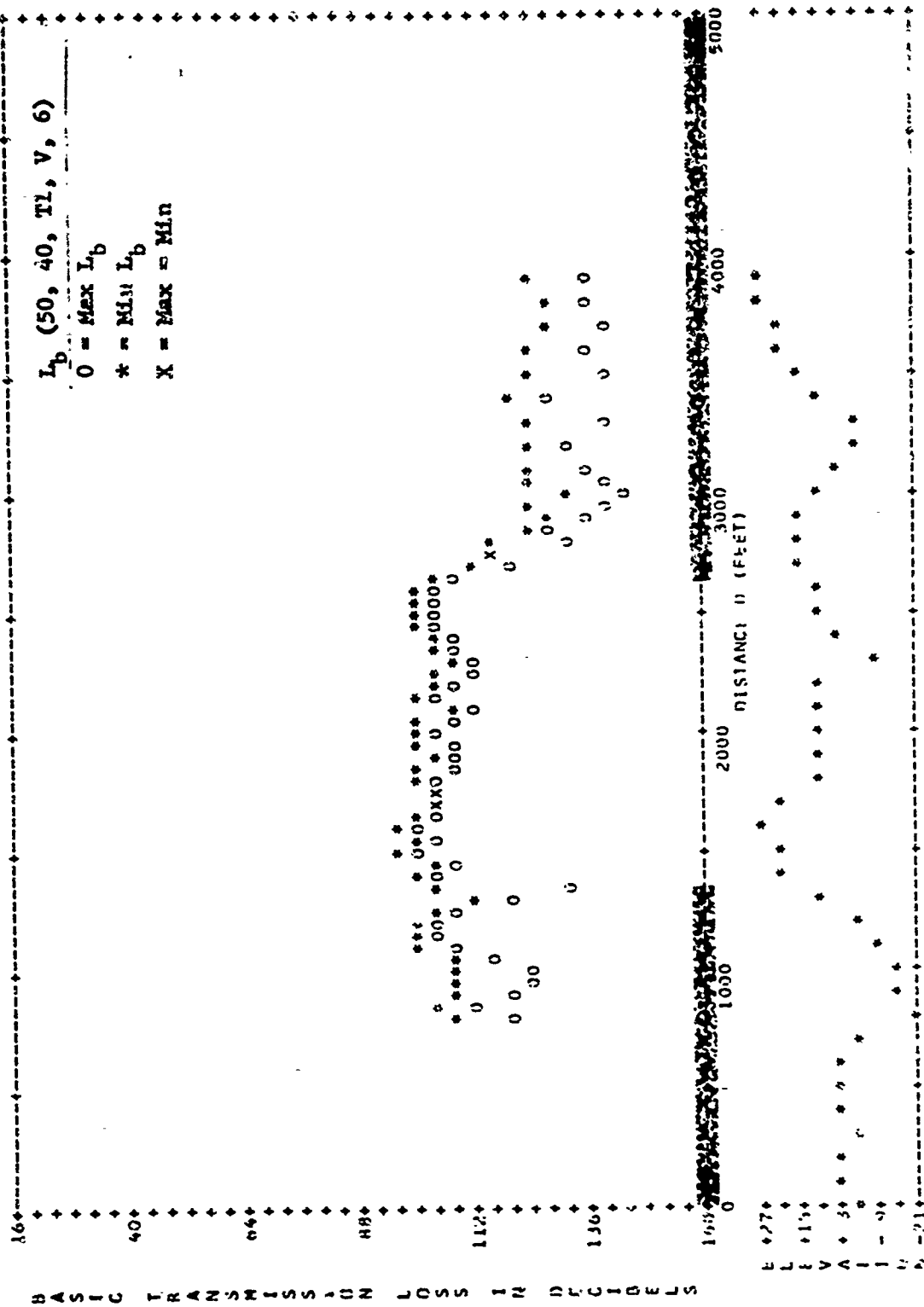


Figure 5.2.4. Basic Transmission Loss and Terrain Elevation vs Distance for Configuration A-2.

MIXED PATH BASIC TRANSMISSION LOSS
WALKING DATA CONFIGURATION A-2, TRANSMITTER 1-1

FREQ = 500000.0 Hz, POL = V

DIST (FT)	MIN (DB)	MAX (DB)	QTS (FT)	MIN (DB)	MAX (DB)
750.0	88.0	121.8	800.0	106.8	121.8
850.0	103.8	118.8	900.0	106.8	118.8
950.0	108.8	124.8	1000.0	107.8	124.8
1050.0	108.8	107.8	1100.0	101.8	107.8
1150.0	99.8	114.8	1200.0	100.8	104.8
1250.0	103.8	105.8	1300.0	110.8	118.8
1350.0	104.8	104.8	1400.0	100.8	105.8
1450.0	104.8	132.8	1500.0	97.8	100.8
1550.0	105.8	107.8	1600.0	96.8	96.8
1650.0	99.8	107.8	1700.0	102.8	104.8
1750.0	98.8	105.8	1800.0	101.8	105.8
1850.0	102.8	104.8	1900.0	102.8	105.8
1950.0	105.8	105.8	2000.0	100.8	104.8
2050.0	100.8	107.8	2100.0	106.8	111.8
2150.0	100.8	105.8	2200.0	105.8	105.8
2250.0	105.8	110.8	2300.0	108.8	112.8
2350.0	105.8	103.8	2400.0	102.8	108.8
2450.0	100.8	105.8	2500.0	101.8	104.8
2550.0	99.8	102.8	2600.0	100.8	105.8
2650.0	101.8	103.8	2700.0	111.8	118.8
2750.0	116.8	117.8	2800.0	117.8	133.8
2850.0	123.8	127.8	2900.0	129.8	136.8
2950.0	123.8	141.8	3000.0	130.8	142.8
3050.0	122.8	141.8	3100.0	123.8	135.8
3150.0	110.8	111.8	3200.0	125.8	133.8
3250.0	110.8	110.8	3300.0	125.8	140.8
3350.0	110.8	110.8	3400.0	119.8	128.8
3450.0	110.8	110.8	3500.0	124.8	138.8
3550.0	110.8	110.8	3600.0	122.8	135.8
3650.0	110.8	110.8	3700.0	128.8	138.8
3750.0	110.8	110.8	3800.0	126.8	134.8
3850.0	110.8	110.8	3900.0	122.8	134.8

Figure 5.2.4 (continued)

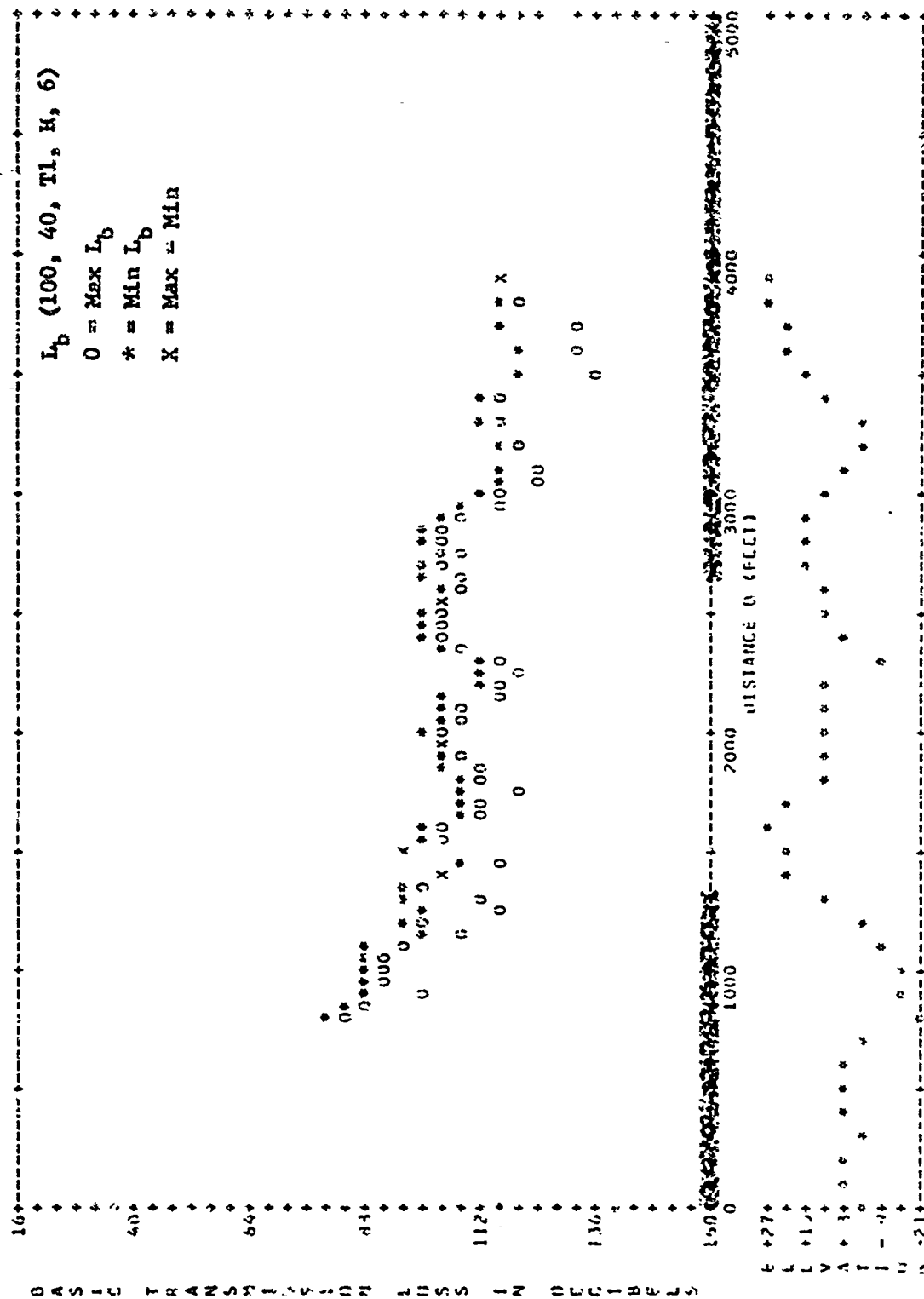


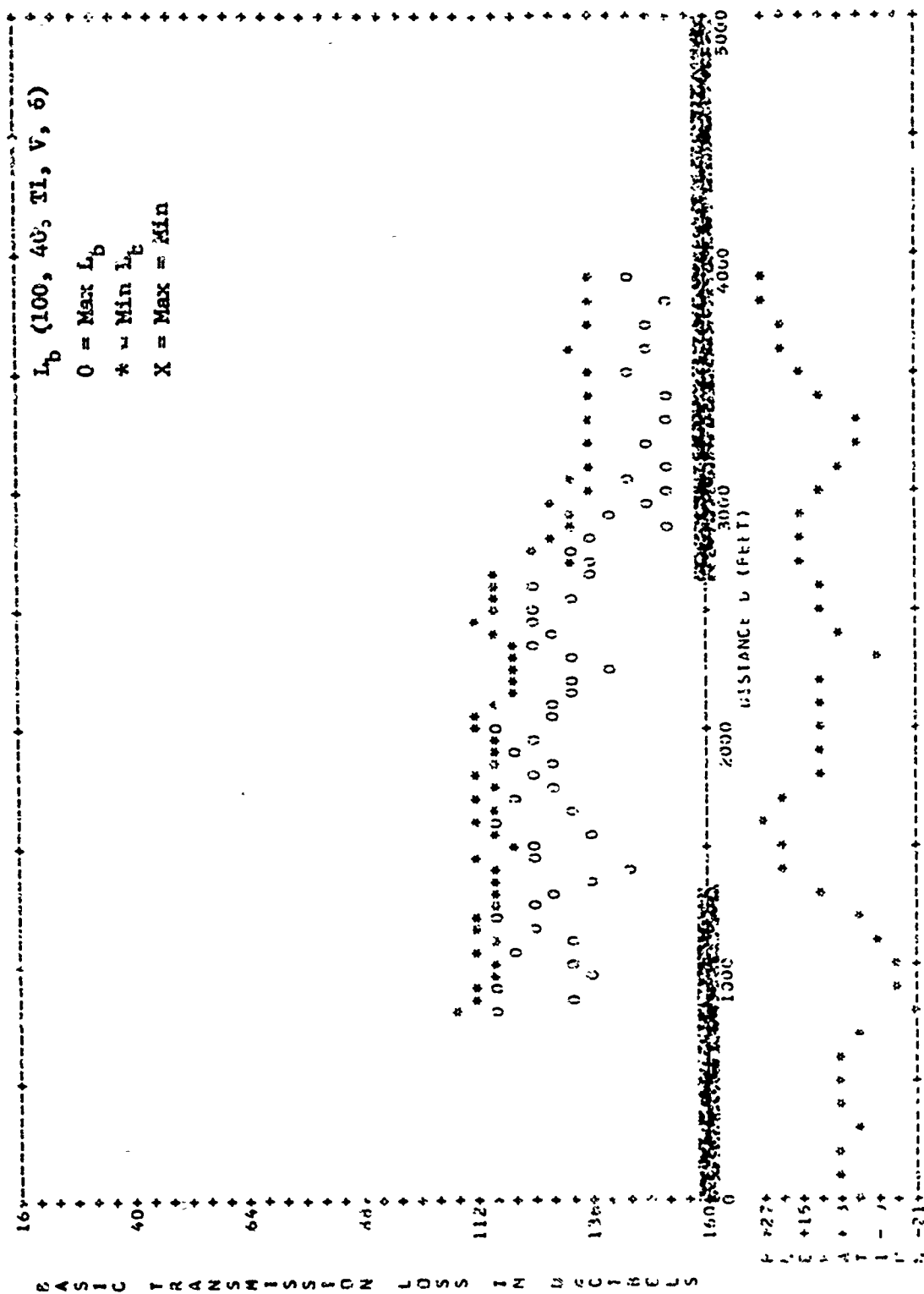
Figure 5.2.5. Basic Transmission Loss and Terrain Elevation vs Distance for Configuration A-2.

MIXED PATH BASIC TRANSMISSION LOSS
 WALKING DATA CONFIGURATION, A-2, TRANSMITTER T-1

FPLD=100MHZ,PH= 40FT,POL=H

HIST(FT)	MINL(OR)	MAXL(OR)	DIST(FT)	MINL(OR)	MAXL(OR)
750.0	84.9	84.9	800.0	81.9	84.9
850.0	84.9	84.9	900.0	89.9	84.9
950.0	87.9	90.9	1000.0	89.9	92.9
1050.0	88.9	91.9	1100.0	89.9	97.9
1150.0	101.9	104.9	1200.0	94.9	101.9
1250.0	98.9	116.9	1300.0	97.9	113.9
1350.0	96.9	100.9	1400.0	102.9	105.9
1450.0	100.9	106.9	1500.0	95.9	97.9
1550.0	100.9	107.9	1600.0	101.9	104.9
1650.0	108.9	111.9	1700.0	106.9	112.9
1750.0	108.9	118.9	1800.0	106.9	112.9
1850.0	104.9	110.9	1900.0	103.9	106.9
1950.0	102.9	105.9	2000.0	100.9	102.9
2050.0	107.9	108.9	2100.0	105.9	107.9
2150.0	105.9	115.9	2200.0	112.9	116.9
2250.0	112.9	118.9	2300.0	113.9	116.9
2350.0	103.9	107.9	2400.0	100.9	102.9
2450.0	109.9	104.9	2500.0	101.9	104.9
2550.0	107.9	109.9	2600.0	103.9	106.9
2650.0	101.9	101.9	2700.0	99.9	102.9
2750.0	103.9	107.9	2800.0	101.9	105.9
2850.0	103.9	103.9	2900.0	103.9	108.9
2950.0	100.9	114.9	3000.0	110.9	114.9
3050.0	114.9	124.9	3100.0	116.9	125.9
3150.0	114.9	114.9	3200.0	114.9	118.9
3250.0	114.9	114.9	3300.0	112.9	117.9
3350.0	114.9	114.9	3400.0	112.9	117.9
3450.0	114.9	114.9	3500.0	113.9	117.9
3550.0	114.9	114.9	3600.0	118.9	130.9
3650.0	114.9	114.9	3700.0	117.9	133.9
3750.0	114.9	114.9	3800.0	115.9	114.9
3850.0	114.9	114.9	3900.0	114.9	117.9

Figure 5.2.5. (continued)



MIXED PATH BASIC TRANSMISSION LOSS
 FALKING DATA CONFIGURATION A-2, TRANSMITTER T-1

FREQ.=1000HZ, HT.= 40FT., PUL.=V

DIST(FT)	MINL(DB)	MAXL(DB)	DIST(FT)	MINL(DB)	MAXL(DB)
150.0	113.8	113.8	800.0	108.8	115.8
850.0	114.9	115.9	900.0	113.9	117.9
950.0	115.9	116.9	1000.0	117.9	123.9
1050.0	116.4	116.9	1100.0	118.9	124.9
1150.0	116.9	116.9	1200.0	119.9	124.9
1250.0	117.9	116.9	1300.0	120.9	124.9
1350.0	117.9	116.9	1400.0	120.9	124.9
1450.0	117.9	116.9	1500.0	120.9	124.9
1550.0	117.9	116.9	1600.0	120.9	124.9
1650.0	117.9	116.9	1700.0	120.9	124.9
1750.0	117.9	116.9	1800.0	120.9	124.9
1850.0	117.9	116.9	1900.0	120.9	124.9
1950.0	117.9	116.9	2000.0	120.9	124.9
2050.0	117.9	116.9	2100.0	120.9	124.9
2150.0	117.9	116.9	2200.0	120.9	124.9
2250.0	117.9	116.9	2300.0	120.9	124.9
2350.0	117.9	116.9	2400.0	120.9	124.9
2450.0	117.9	116.9	2500.0	120.9	124.9
2550.0	117.9	116.9	2600.0	120.9	124.9
2650.0	117.9	116.9	2700.0	120.9	124.9
2750.0	117.9	116.9	2800.0	120.9	124.9
2850.0	117.9	116.9	2900.0	120.9	124.9
2950.0	117.9	116.9	3000.0	120.9	124.9
3050.0	117.9	116.9	3100.0	120.9	124.9
3150.0	117.9	116.9	3200.0	120.9	124.9
3250.0	117.9	116.9	3300.0	120.9	124.9
3350.0	117.9	116.9	3400.0	120.9	124.9
3450.0	117.9	116.9	3500.0	120.9	124.9
3550.0	117.9	116.9	3600.0	120.9	124.9
3650.0	117.9	116.9	3700.0	120.9	124.9
3750.0	117.9	116.9	3800.0	120.9	124.9
3850.0	117.9	116.9	3900.0	120.9	124.9

Figure 5.2.6 (continued)

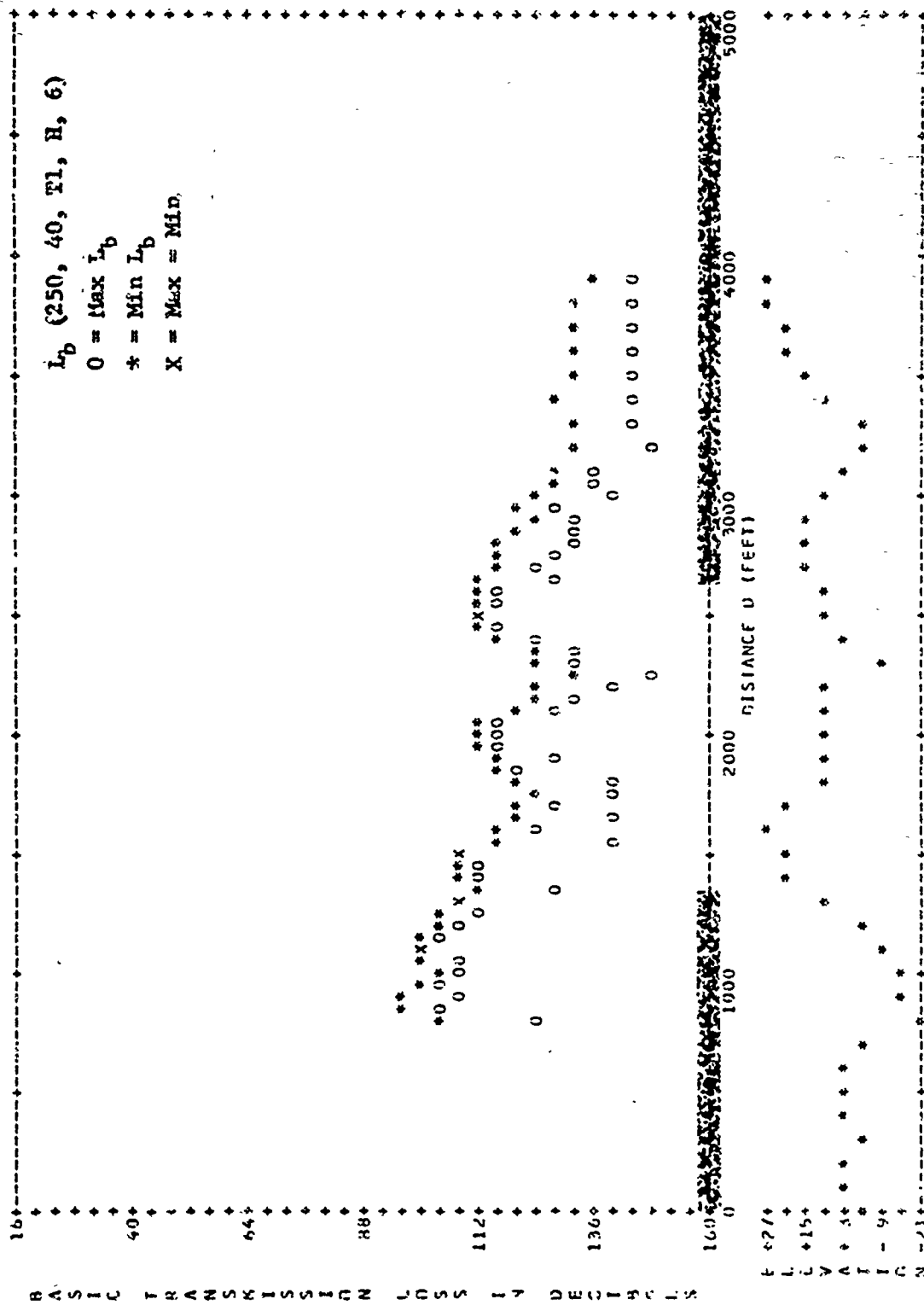


Figure 5.2.7. Basic Transmission Loss and Terrain Elevation vs Distance for Configuration A-2.

FIXED PATH BASIC TRANSMISSION LOSS
 WAKEING DATA CONFIGURATION 0-2, TRANSMISSION 1-1

5710.0-250MHZ, H1.7 401.0, PCL.3R

DISTANCE	MINIMUM	MAXIMUM	DISTANCE	MINIMUM	MAXIMUM
750.0	95.5	102.5	900.0	95.5	102.5
850.0	95.5	104.5	1000.0	95.5	102.5
950.0	101.5	108.5	1100.0	98.5	104.5
1050.0	98.5	105.5	1200.0	98.5	104.5
1150.0	98.5	111.5	1300.0	106.5	108.5
1250.0	112.5	124.5	1400.0	106.5	108.5
1350.0	109.5	117.5	1500.0	106.5	108.5
1450.0	106.5	114.5	1600.0	106.5	108.5
1550.0	106.5	114.5	1700.0	119.5	123.5
1650.0	126.5	141.5	1800.0	119.5	123.5
1750.0	114.5	119.5	1900.0	119.5	123.5
1850.0	111.5	116.5	2000.0	119.5	123.5
1950.0	111.5	114.5	2100.0	123.5	128.5
2050.0	123.5	132.5	2200.0	123.5	128.5
2150.0	137.5	148.5	2300.0	123.5	128.5
2250.0	124.5	131.5	2400.0	123.5	128.5
2350.0	111.5	116.5	2500.0	113.5	113.5
2450.0	111.5	110.5	2600.0	113.5	113.5
2550.0	111.5	129.5	2700.0	113.5	113.5
2650.0	115.5	126.5	2800.0	115.5	115.5
2750.0	120.5	130.5	2900.0	122.5	122.5
2850.0	117.5	124.5	3000.0	122.5	122.5
2950.0	129.5	136.5	3100.0	127.5	127.5
3050.0	129.5	136.5	3200.0	131.5	131.5
3150.0	129.5	136.5	3300.0	131.5	131.5
3250.0	129.5	136.5	3400.0	131.5	131.5
3350.0	129.5	136.5	3500.0	131.5	131.5
3450.0	129.5	136.5	3600.0	131.5	131.5
3550.0	129.5	136.5	3700.0	131.5	131.5
3650.0	129.5	136.5	3800.0	131.5	131.5
3750.0	129.5	136.5	3900.0	131.5	131.5
3850.0	129.5	136.5			
3950.0	129.5	136.5			

Figure 5.2.7 (continued)

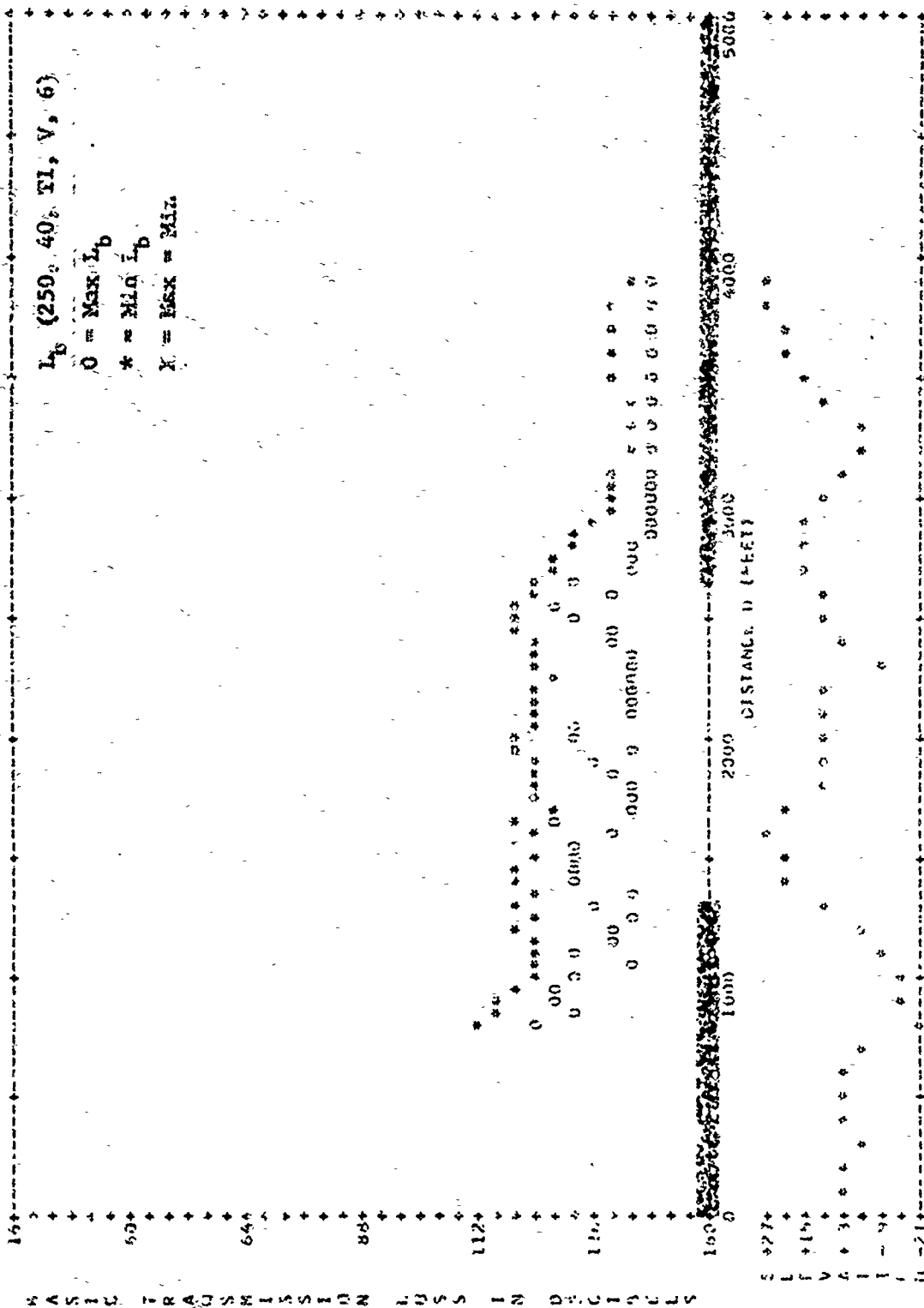


Figure 5.2.8. Basic Transmission Loss and Terrain Elevation vs Distance for Configuration A-2.

MIXED PATH BASIC TRANSMISSION LOSS
WALKING DATA CONFIGURATION A-2, TRANSMITTER T-1
FREQ.=250MHZ, HT.= 40FT., POL.=V

DIST(FT)	MINLR(DB)	MAXLR(DB)	DESL(FT)	MINLR(DB)	MAXLR(DB)
750.0	***	***	800.0	111.9	122.9
850.0	114.9	132.9	900.0	114.9	127.9
950.0	119.9	129.9	1000.0	126.9	132.9
1050.0	123.9	143.9	1100.0	123.9	132.9
1150.0	125.9	140.9	1200.0	120.9	130.9
1250.0	125.9	142.9	1300.0	121.9	135.9
1350.0	125.9	145.9	1400.0	119.9	131.9
1450.0	120.9	130.9	1500.0	123.9	131.9
1550.0	120.9	132.9	1600.0	123.9	136.9
1650.0	119.9	127.9	1700.0	127.9	144.9
1750.0	124.9	142.9	1800.0	126.9	142.9
1850.0	123.9	140.9	1900.0	122.9	136.9
1950.0	121.9	144.9	2000.0	119.9	130.9
2050.0	122.9	133.9	2100.0	124.9	142.9
2150.0	125.9	142.9	2200.0	125.9	144.9
2250.0	129.9	144.9	2300.0	124.9	142.9
2350.0	125.9	144.9	2400.0	123.9	141.9
2450.0	114.9	131.9	2500.0	121.9	130.9
2550.0	119.9	129.9	2600.0	122.9	139.9
2650.0	125.9	132.9	2700.0	120.9	144.9
2750.0	126.9	144.9	2800.0	130.9	144.9
2850.0	133.9	146.9	2900.0	135.9	147.9
2950.0	140.9	140.9	3000.0	141.9	148.9
3050.0	***	***	3100.0	141.9	149.9
3150.0	***	***	3200.0	142.9	148.9
3250.0	***	***	3300.0	144.9	148.9
3350.0	***	***	3400.0	138.9	147.9
3450.0	***	***	3500.0	140.9	147.9
3550.0	***	***	3600.0	139.9	148.9
3650.0	***	***	3700.0	140.9	148.9
3750.0	***	***	3800.0	143.9	145.9
3850.0	***	***	3900.0		

Figure 5.2.8 (continued)

8	15	23	28	RECEIVE HEIGHT (FEET)							CONF	TRANS-REC	SYM	DIST (Mi)
				34	40	45	50	55	60	65				
95	91	89	87	85	84	83	82	82	82	81	A2	T1-R1	0	0.740
97	95	93	90	88	86	84	83	82	81	80	A2	T1-R2	*	0.587
91	82	79	77	76	74	73	72	72	72	71	A2	T1-R3	.	0.475
82	75	73	70	68	67	66	66	66	66	65	A2	T1-R4	*	0.267

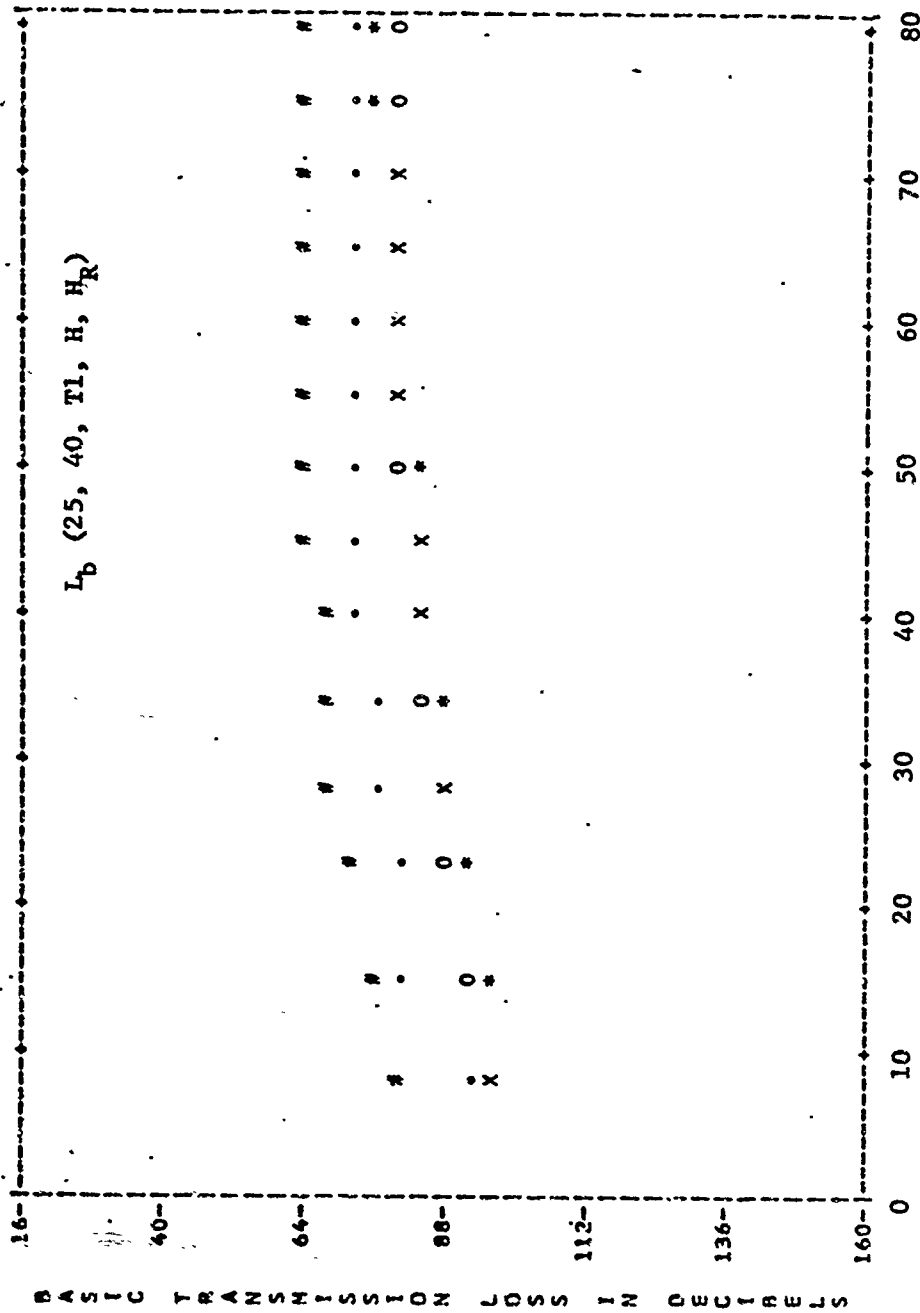


Figure 5.2.9 Basic Transmission Loss vs Receive Antenna Height for Configuration A-2

	RECEIVE HEIGHT (FEET)										CONF	TRANS-REC	SYM	DIST (Mi)				
	8	15	23	28	34	40	45	50	55	60					65	70	75	80
123	120	115	113	110	108	106	105	104	103	101	100	100	100	100	A2	T1-R1	0	0.740
114	115	110	107	106	105	104	103	101	99	96	94	94	94	95	A2	T1-R2	*	0.587
89	90	93	95	93	89	87	86	86	85	83	83	83	83	82	A2	T1-R3	.	0.475
90	93	94	93	86	81	80	81	81	82	81	80	79	79	79	A2	T1-R4	#	0.267

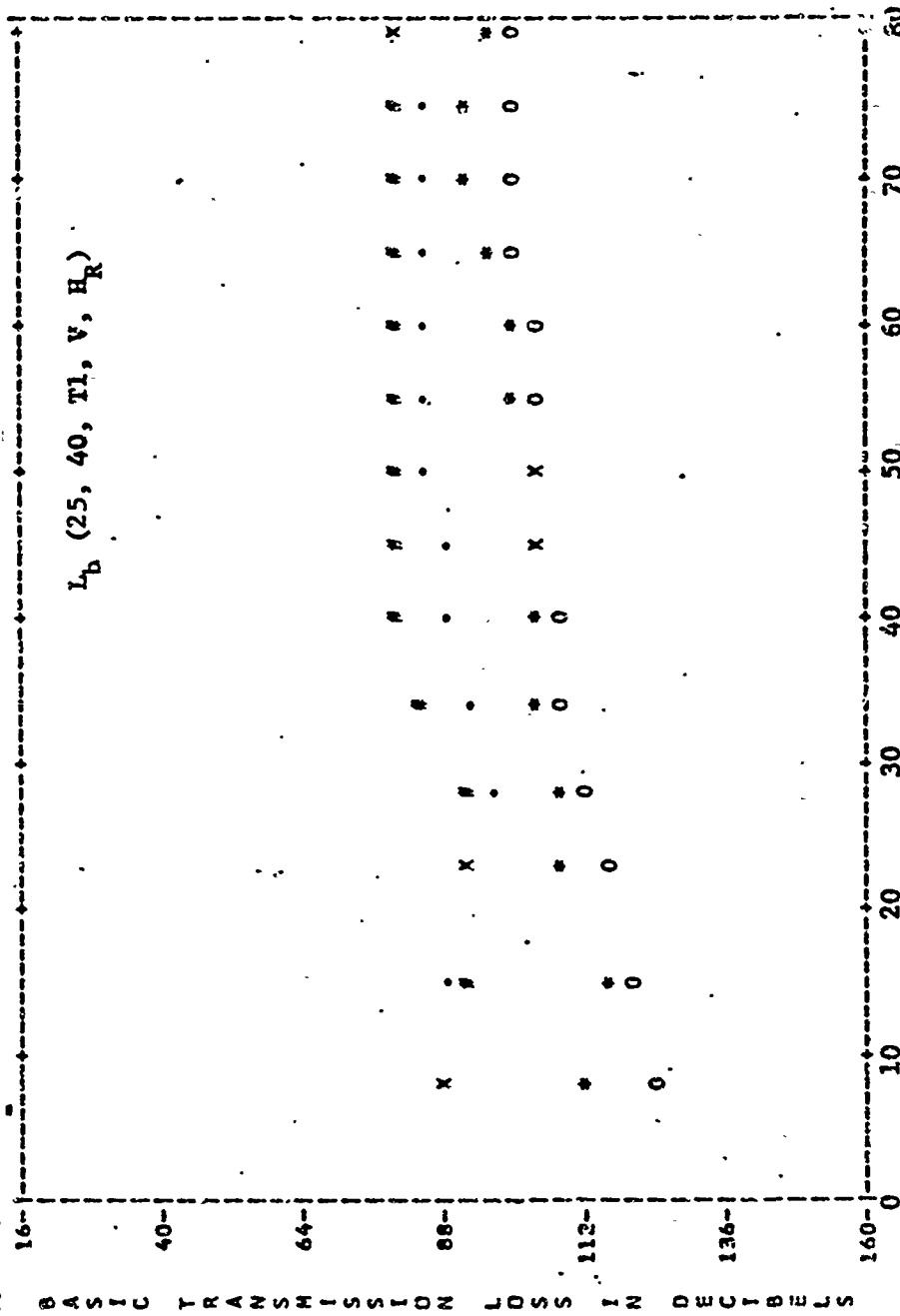


Figure 5.2.10 Basic Transmission Loss vs Receive Antenna Height for Configuration A-2

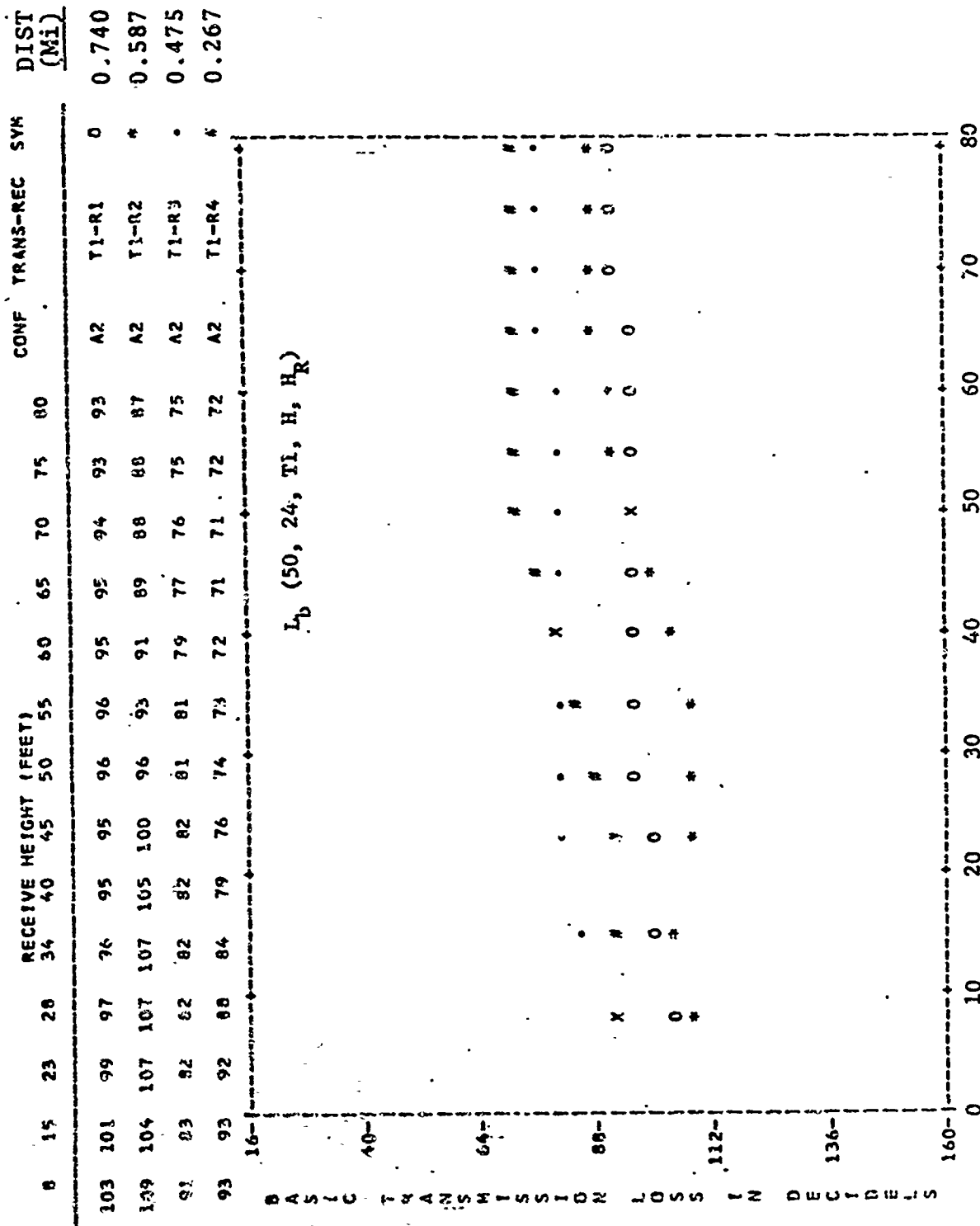


Figure 5.2.11 Basic Transmission Loss vs Receive Antenna Height for Configuration A-2

8	15	23	28	34	40	45	50	55	60	65	70	75	80	CONF	TRANS-REC	SYM	DIST (Mi)
125	125	128	128	125	121	119	119	119	114	108	105	104	104	A2	Y1-R1	0	0.740
129	121	121	121	120	123	126	123	119	116	113	111	109	108	A2	Y1-R2	*	0.587
101	97	95	95	94	93	92	92	91	92	92	90	90	89	A2	Y1-R3	.	0.475
100	99	95	92	92	92	90	89	88	86	85	85	84	83	A2	Y1-R4	#	0.267

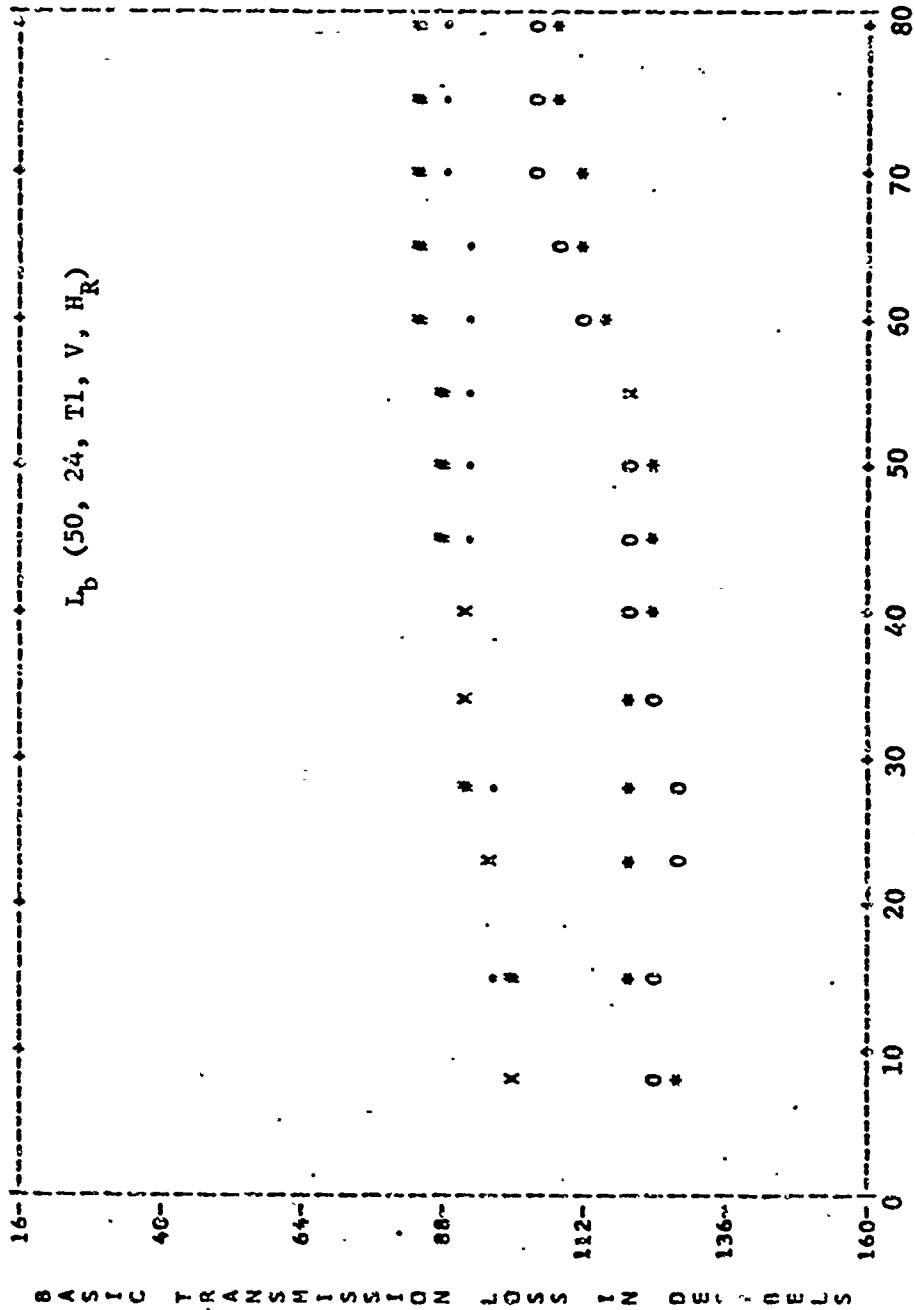


Figure 5.2.12 Basic Transmission Loss vs Receive Antenna Height for Configuration A-2

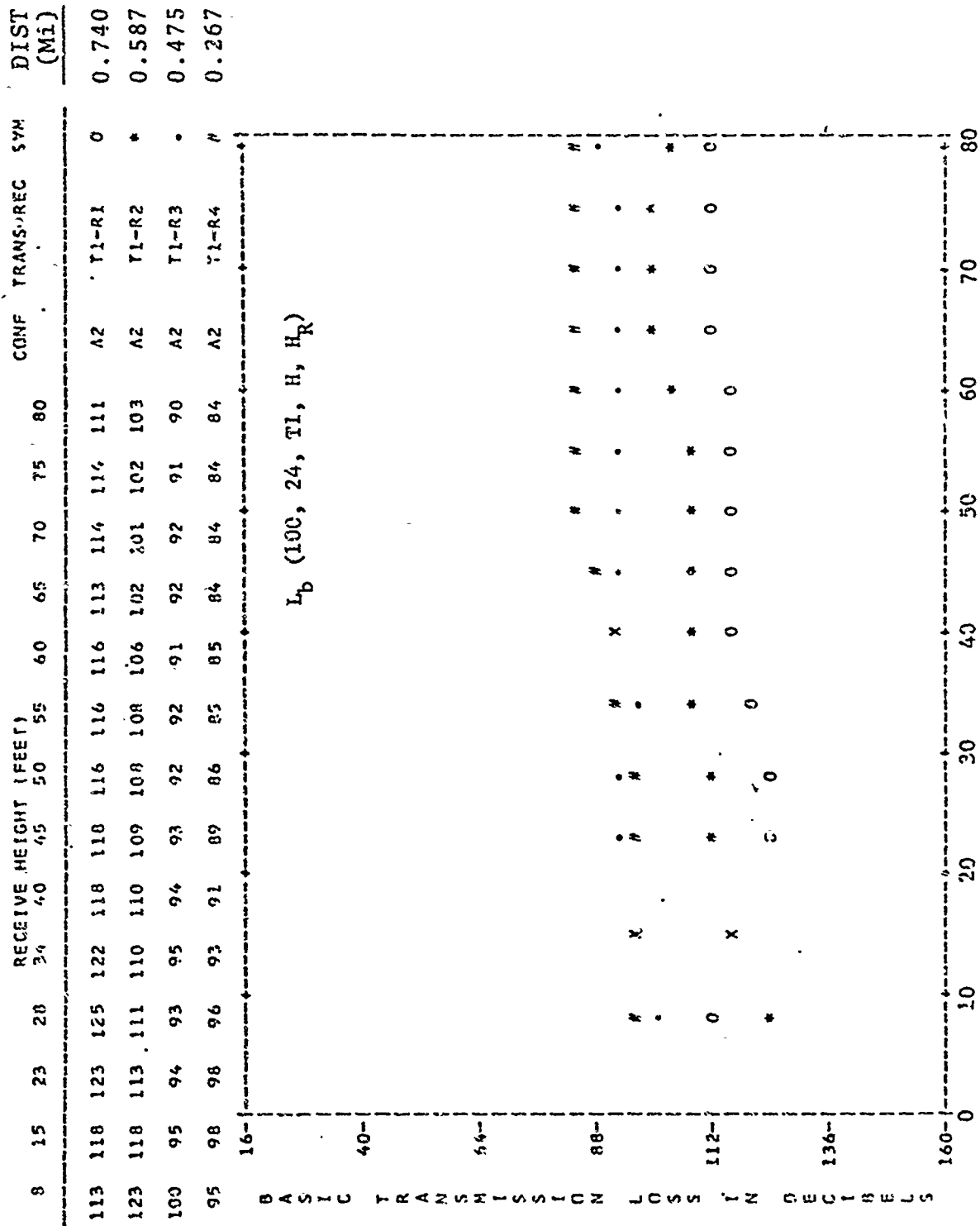


Figure 5.2.13 Basic Transmission Loss vs Receive Antenna Height for Configuration A-2

8	15	23	28	RECEIVE HEIGHT (FEET)											CONF	TRANS-REC	SYM	DIST (Mi)
				34	40	45	50	55	60	65	70	75	80					
131	133	128	128	134	135	138	133	123	121	121	125	121	113	A2	T1-R1	0	0.740	
137	137	129	133	133	127	127	125	122	120	119	116	117	118	A2	T1-R2	*	0.587	
110	107	107	106	105	104	103	104	104	104	103	103	103	103	A2	T1-R3	.	0.475	
111	109	111	110	107	104	101	93	96	95	93	92	92	92	A2	T1-R4	#	0.267	

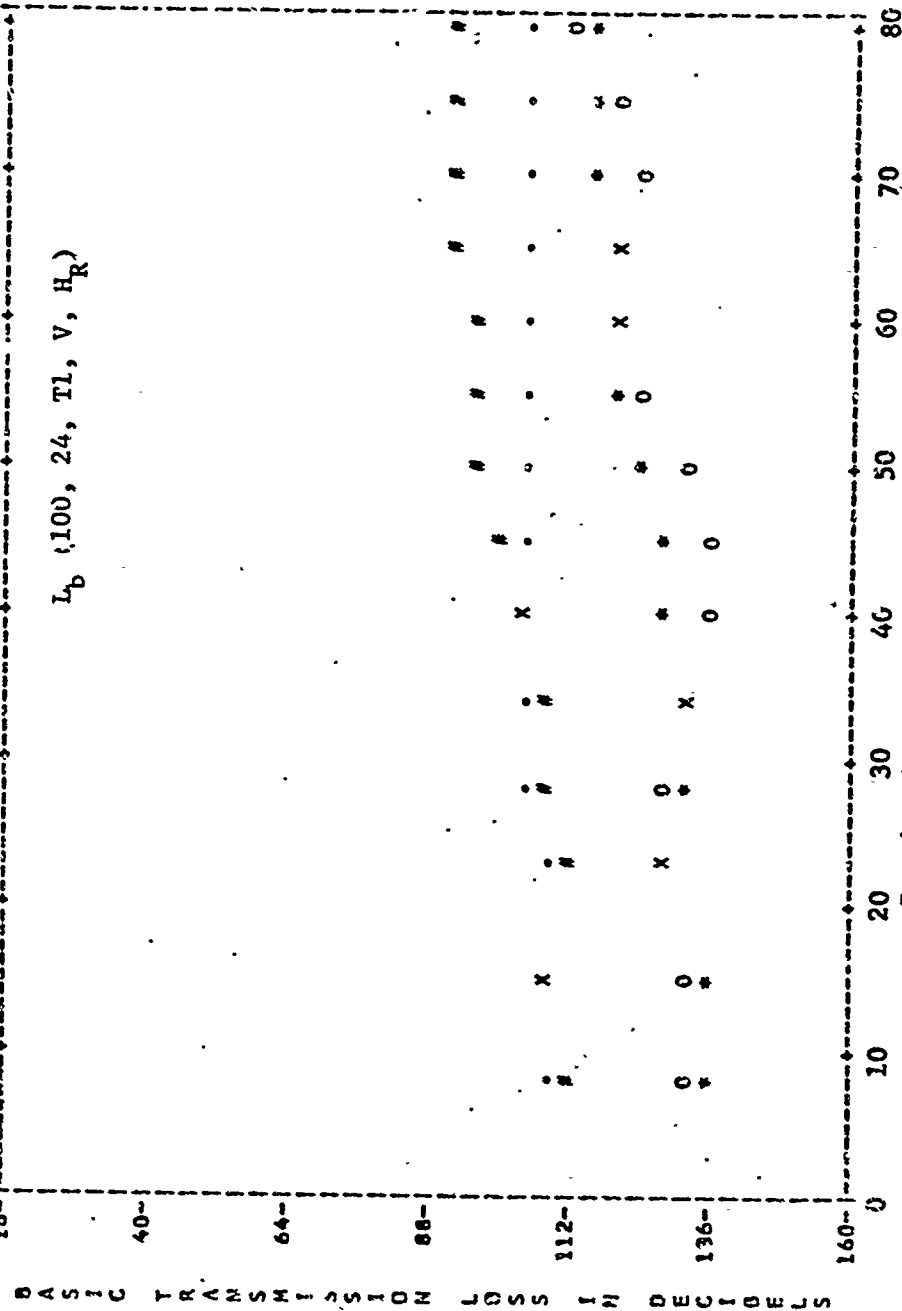


Figure 5.2.14 Basic Transmission Loss vs Receive Antenna Height for Configuration A-2

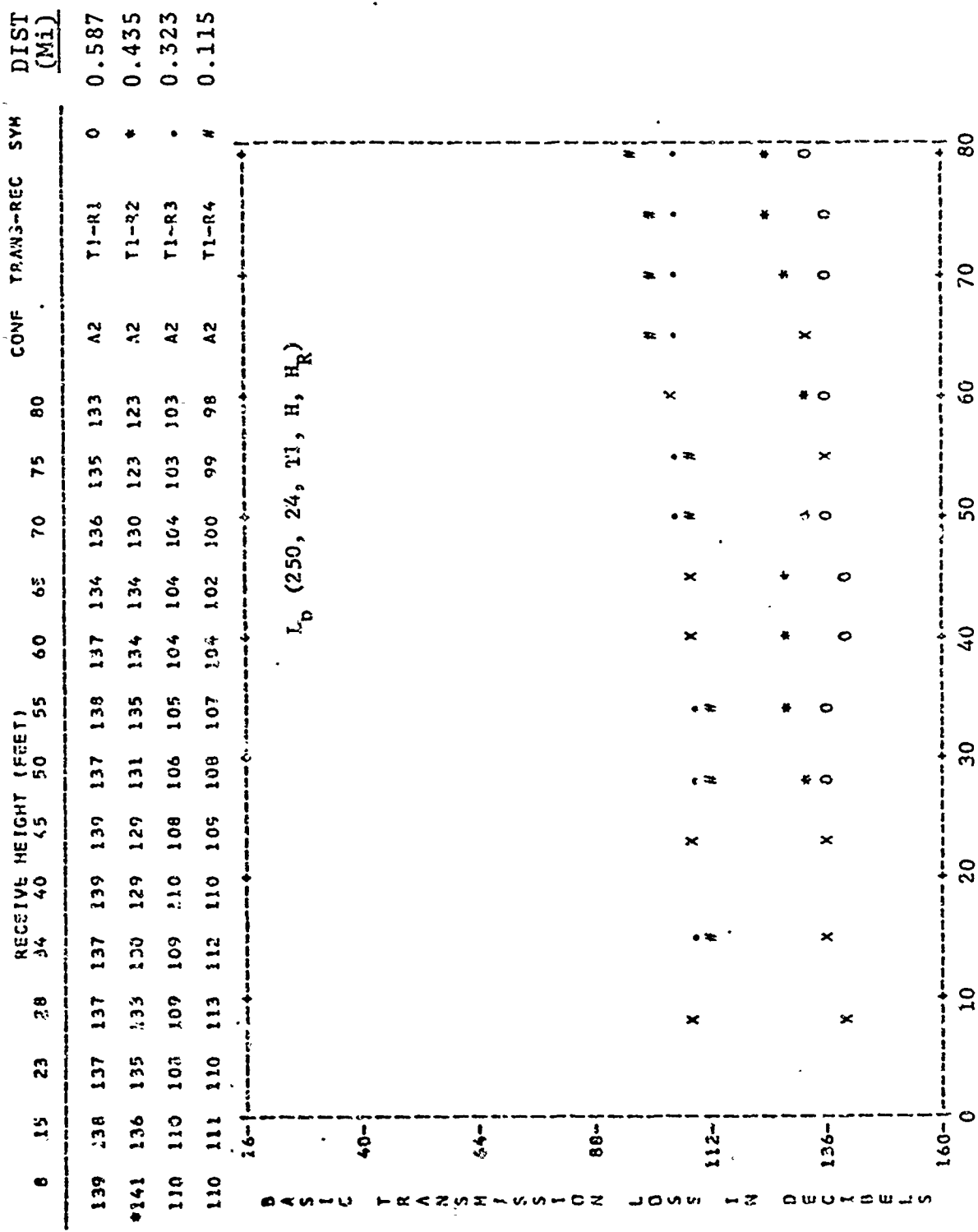


Figure 5.2.15 Basic Transmission Loss vs Receive Antenna Height for Configuration A-2

0	15	23	28	34	RECEIVE HEIGHT (FEET)										CONF	TRANS-REC	SYM	DIST (M)
					45	50	55	60	65	70	75	80						
0	0	0	0	0	141	141	141	141	138	136	136	136	A2	Y1-R1	0	0.740		
149	147	147	146	145	147	143	141	141	142	139	136	135	A2	Y1-R2	*	0.587		
116	116	116	115	114	114	115	115	116	112	112	112	114	A2	Y1-R3	0	0.475		
123	122	121	123	123	124	124	122	119	116	114	109	107	A2	Y1-R4	*	0.267		

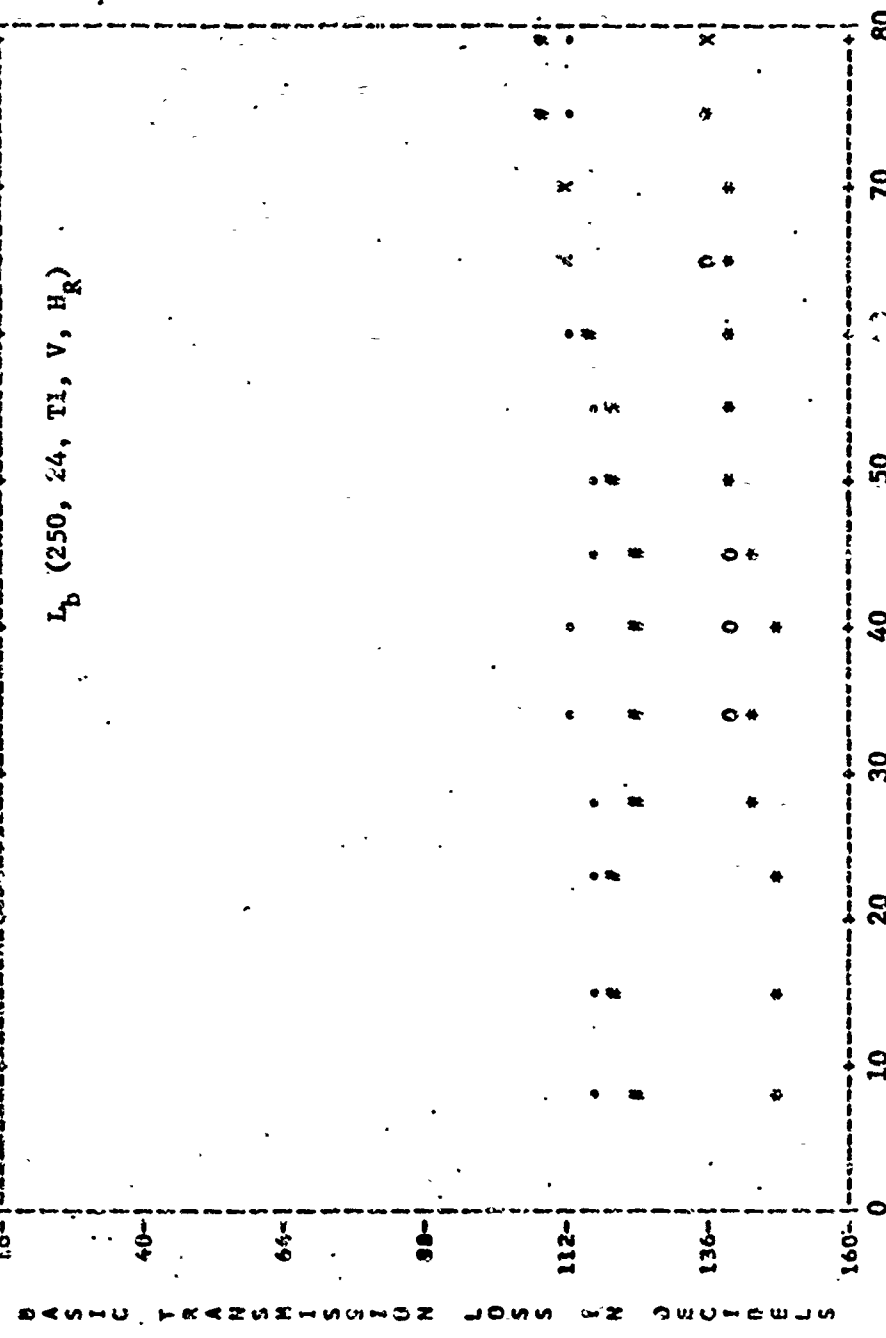


Figure 5.2.16 Basic Transmission Loss vs Receive Antenna Height for Configuration A-2

MIXED PATH BASIC TRANSMISSION LOSS
WALKING DATA CONFIGURATION H-O, TRANSMITTER T-1

FREQ. = 25MHZ., HT. = 40FT., PQL = 11

DIST(FT)	MINLH(DB)	MAXLH(DB)	DIST(FT)	MINLH(DB)	MAXLH(DB)
100.0	35.5	37.5	150.0	****	****
200.0	47.8	****	250.0	****	****
300.0	50.9	51.9	350.0	****	****
400.0	53.7	54.9	450.0	****	****
500.0	57.9	****	550.0	****	****
600.0	60.9	61.9	650.0	****	****
700.0	65.9	66.9	750.0	****	****
800.0	69.9	70.9	850.0	****	****
900.0	72.9	77.9	950.0	****	****
1000.0	72.9	73.7	1050.0	****	****
1100.0	75.9	76.9	1150.0	****	****
1200.0	79.9	85.9	1250.0	****	****
1300.0	85.5	91.9	1350.0	****	****
1400.0	79.9	80.9	1450.0	****	****
1500.0	80.9	81.9	1550.0	****	****
1600.0	76.9	77.9	1650.0	76.9	76.9
1700.0	75.9	77.9	1750.0	75.9	75.9
1800.0	77.9	77.9	1850.0	78.9	80.9
1900.0	78.9	79.9	1950.0	79.9	80.9
2000.0	84.9	86.9	2050.0	91.9	****
2100.0	87.9	88.9	2150.0	84.9	111.9
2200.0	90.9	92.4	2250.0	****	****
2300.0	93.9	96.9	2350.0	****	****
2400.0	91.9	97.9	2450.0	****	****
2500.0	91.9	95.9	2550.0	****	****
2600.0	91.9	91.9	2650.0	****	****
2700.0	90.9	91.9	2750.0	****	****
2800.0	89.9	91.9	2850.0	****	****
2900.0	87.9	89.9	2950.0	****	****
3000.0	90.9	91.9	3050.0	****	****
3100.0	92.9	95.9	3150.0	****	****
3200.0	91.9	99.9	3250.0	****	****
3300.0	96.9	97.9	3350.0	****	****
3400.0	97.9	101.9	3450.0	101.9	103.9
3500.0	97.9	99.9	3550.0	98.9	104.9
3600.0	103.9	107.9	3650.0	96.9	96.9
3700.0	93.9	95.9	3750.0	97.9	99.9
3800.0	91.9	****	3850.0	52.9	93.9
3900.0	90.9	91.9	3950.0	91.9	77.9
4000.0	92.9	93.9	4050.0	91.9	****
4100.0	91.9	92.9	4150.0	91.9	****
4200.0	90.9	91.9	4250.0	90.9	92.9
4300.0	91.9	92.9	4350.0	92.9	93.9
4400.0	92.9	93.9	4450.0	93.9	94.9
4500.0	92.9	94.9	4550.0	93.9	94.9
4600.0	93.9	97.9	4650.0	93.9	97.9
4700.0	95.9	100.9	4750.0	95.9	97.9

Figure 5.2.17 (continued)

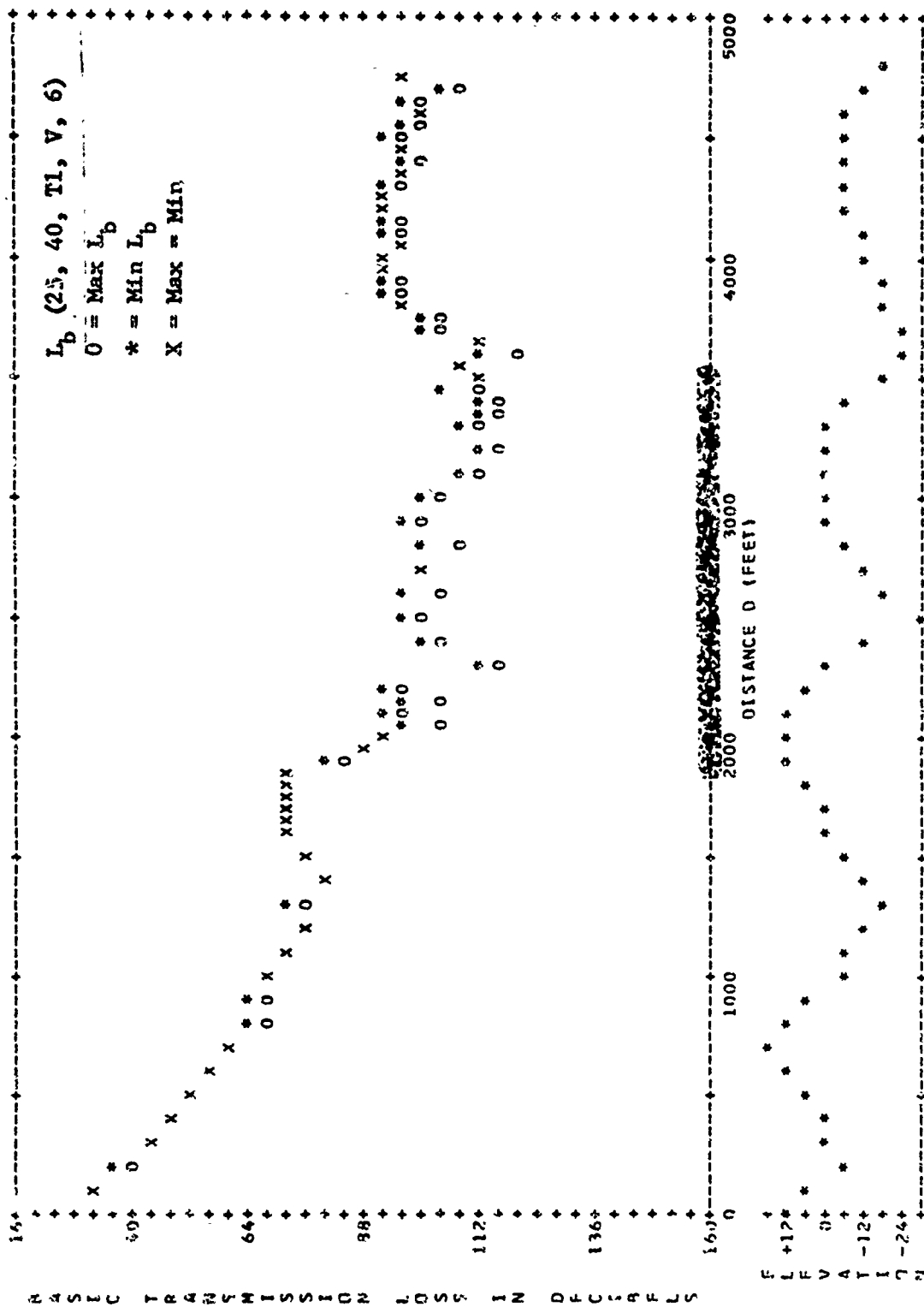


Figure 5.2.18. Basic Transmission Loss and Terrain Elevation vs Distance for Configuration B-0.

MIXED PATH BASIC TRANSMISSION LOSS
WALKING DATA CONFIGURATION B-O, TRANSMITTER T-1
FREQ.= 25MHz, HT.= 40FT., POL.=V

DIST(FT)	MINLB(DB)	MAXLB(DB)	DISL(FT)	KINLB(DB)	MAXLB(DB)
200.0	30.5	30.5	150.0	*****	*****
300.0	38.0	39.0	250.0	*****	*****
400.0	44.1	45.1	350.0	*****	*****
500.0	46.2	49.2	450.0	*****	*****
600.0	51.2	51.2	550.0	*****	*****
700.0	54.2	55.2	650.0	*****	*****
800.0	59.2	60.2	750.0	*****	*****
900.0	65.2	66.2	850.0	*****	*****
1000.0	67.2	67.2	950.0	*****	*****
1100.0	70.2	68.2	1050.0	*****	*****
1200.0	75.2	71.2	1150.0	*****	*****
1300.0	73.2	76.2	1250.0	*****	*****
1400.0	79.2	75.2	1350.0	*****	*****
1500.0	75.2	80.2	1450.0	*****	*****
1600.0	71.2	75.2	1550.0	*****	*****
1700.0	70.2	72.2	1650.0	71.2	71.2
1800.0	71.2	72.2	1750.0	71.2	73.2
1900.0	81.2	84.2	1850.0	87.2	73.2
2000.0	91.2	93.2	1950.0	97.2	89.2
2100.0	93.2	94.2	2050.0	97.2	105.2
2200.0	93.2	95.2	2150.0	97.2	105.2
2300.0	112.2	114.2	2250.0	*****	*****
2400.0	100.2	105.2	2350.0	*****	*****
2500.0	97.2	98.2	2450.0	*****	*****
2600.0	97.2	103.2	2550.0	*****	*****
2700.0	98.2	100.2	2650.0	*****	*****
2800.0	99.2	106.2	2750.0	*****	*****
2900.0	96.2	106.2	2850.0	*****	*****
3000.0	101.2	98.2	2950.0	*****	*****
3100.0	106.2	103.2	3050.0	*****	*****
3200.0	110.2	111.2	3150.0	*****	*****
3300.0	109.2	115.2	3250.0	*****	*****
3400.0	113.2	113.2	3350.0	111.2	115.2
3500.0	110.2	117.2	3450.0	102.2	110.2
3600.0	113.2	113.2	3550.0	107.2	109.2
3700.0	99.2	119.2	3650.0	110.2	113.2
3800.0	96.2	105.2	3750.0	100.2	103.2
3900.0	93.2	97.2	3850.0	93.2	94.2
4000.0	93.2	95.2	3950.0	91.2	92.2
4100.0	93.2	95.2	4050.0	91.2	95.2
4200.0	91.2	93.2	4150.0	92.2	94.2
4300.0	93.2	93.2	4250.0	91.2	92.2
4400.0	94.2	94.2	4350.0	95.2	97.2
4500.0	93.2	94.2	4450.0	96.2	97.2
4600.0	90.2	95.2	4550.0	97.2	99.2
4700.0	105.2	107.2	4650.0	97.2	98.2
			4750.0	95.2	97.2

Figure 5.2.18 (continued)

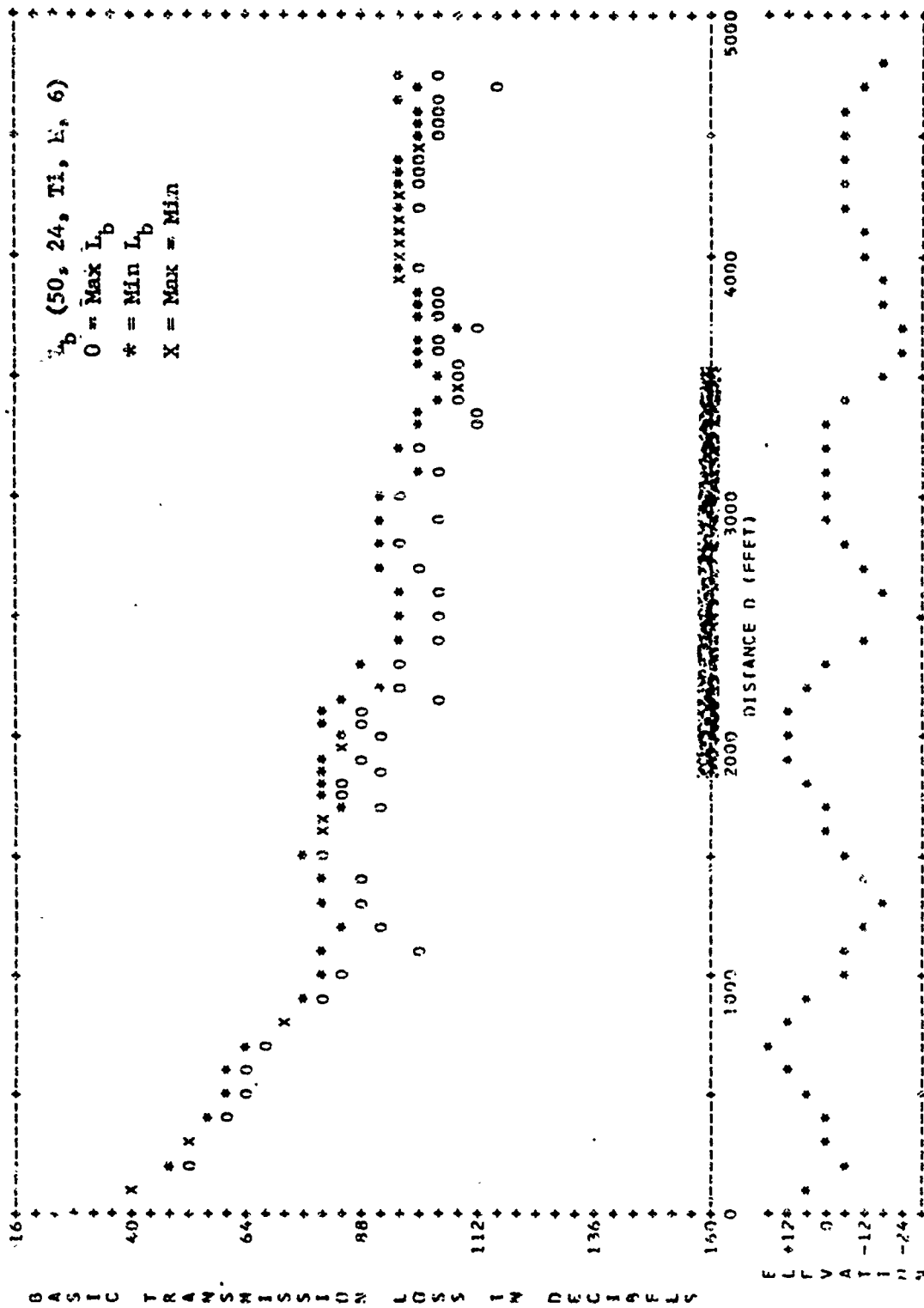


Figure 5.2.19. Basic Transmission Loss and Terrain Elevation vs Distance for Configuration B-0.

MIXED PATH BASIC TRANSMISSION LOSS
WALKING DATA CONFIGURATION R-O, TRANSMITTER T-1

FRQ.= 50MHZ, HT.= 40FT., PUL.=11

DIST(FT)	MINL(B(DR)	MAXL(B(DR)	DIST(FT)	MINL(B(DR)	MAXL(B(DR)
100.0	38.6	51.6	150.0	*****	*****
200.0	44.6	50.6	250.0	*****	*****
300.0	52.6	53.6	350.0	*****	*****
400.0	57.6	58.6	450.0	*****	*****
500.0	61.6	62.6	550.0	*****	*****
600.0	61.6	63.6	650.0	*****	*****
700.0	64.6	66.6	750.0	*****	*****
800.0	70.6	72.6	850.0	*****	*****
900.0	74.6	76.6	950.0	*****	*****
1000.0	78.6	83.6	1050.0	*****	*****
1100.0	80.6	84.6	1150.0	*****	*****
1200.0	83.6	86.6	1250.0	*****	*****
1300.0	79.6	81.6	1350.0	*****	*****
1400.0	81.6	86.6	1450.0	*****	*****
1500.0	77.6	79.6	1550.0	*****	*****
1600.0	79.6	81.6	1650.0	79.6	81.6
1700.0	85.6	91.6	1750.0	81.6	83.6
1800.0	78.6	84.6	1850.0	79.6	90.6
1900.0	74.6	86.6	1950.0	82.6	85.6
2000.0	84.6	92.6	2050.0	78.6	86.6
2100.0	80.6	89.6	2150.0	82.6	105.6
2200.0	90.6	94.6	2250.0	*****	*****
2300.0	88.6	94.6	2350.0	*****	*****
2400.0	97.6	102.6	2450.0	*****	*****
2500.0	95.6	102.6	2550.0	*****	*****
2600.0	97.6	105.6	2650.0	*****	*****
2700.0	93.6	99.6	2750.0	*****	*****
2800.0	92.6	95.6	2850.0	*****	*****
2900.0	93.6	104.6	2950.0	*****	*****
3000.0	93.6	94.6	3050.0	*****	*****
3100.0	99.6	102.6	3150.0	*****	*****
3200.0	96.6	100.6	3250.0	*****	*****
3300.0	98.6	110.6	3350.0	101.6	110.6
3400.0	102.6	109.6	3450.0	109.6	109.6
3500.0	102.6	107.6	3550.0	101.6	103.6
3600.0	101.6	105.6	3650.0	100.6	104.6
3700.0	106.6	112.6	3750.0	100.6	102.6
3800.0	101.6	102.6	3850.0	99.6	98.6
3900.0	96.6	97.6	3950.0	97.6	96.6
4000.0	96.6	97.6	4050.0	95.6	96.6
4100.0	94.6	95.6	4150.0	94.6	96.6
4200.0	97.6	98.6	4250.0	96.6	99.6
4300.0	96.6	99.6	4350.0	97.6	99.6
4400.0	97.6	101.6	4450.0	99.6	100.6
4500.0	98.6	102.6	4550.0	98.6	102.6
4600.0	99.6	102.6	4650.0	96.6	103.6
4700.0	98.6	114.6	4750.0	96.6	104.6

Figure 5.2.19 (continued)

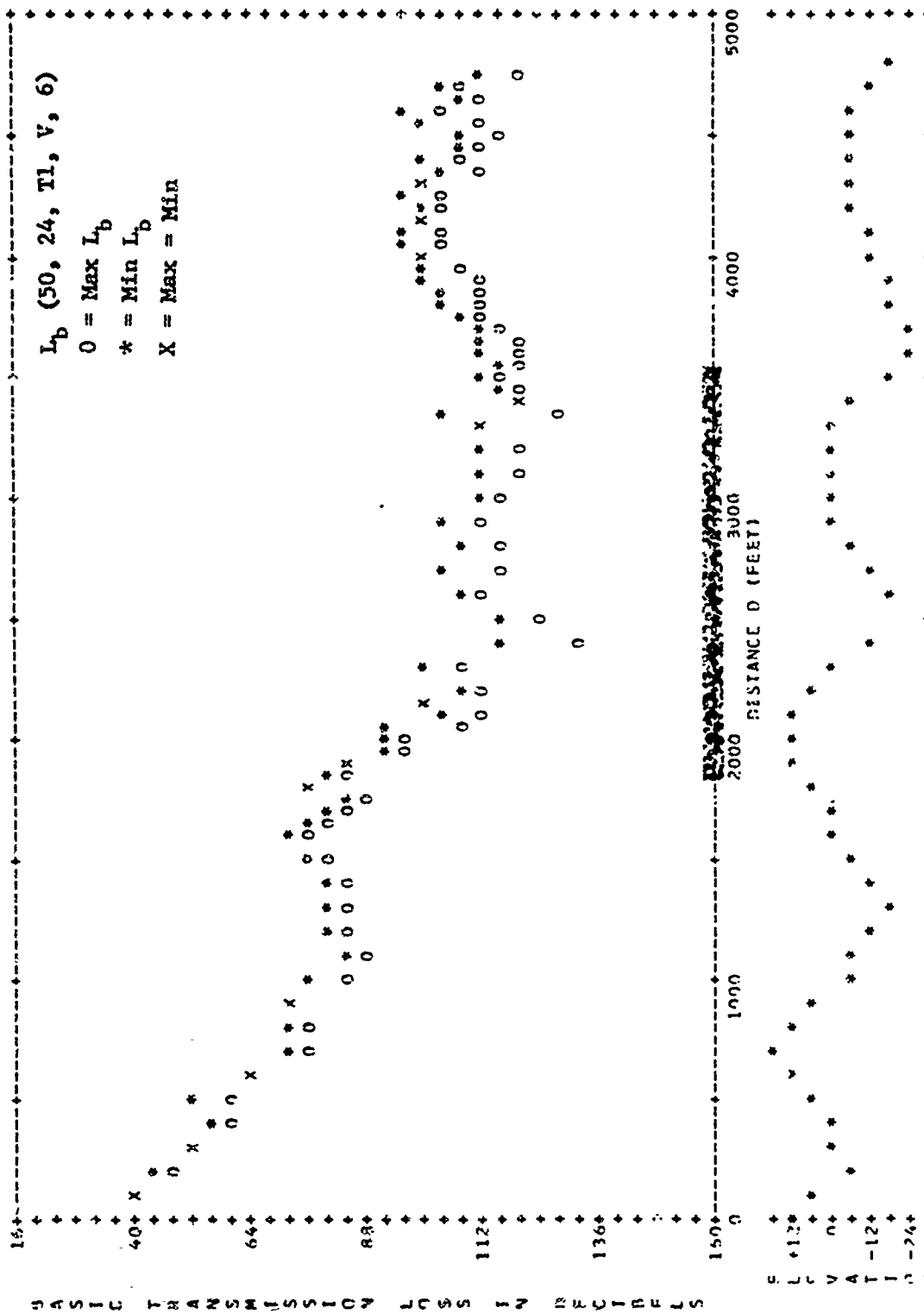


Figure 5.2.20. Basic Transmission Loss and Terrain Elevation vs Distance for Configuration B-0.

MIXED PATH BASIC TRANSMISSION LOSS
WALKING DATA CONFIGURATION 0-0, TRANSMITTER T-1

FREQ. = 50MHZ., MT. = 40FT., PUL. = V

DIST(FT)	MINLR(DR)	MAXLR(DR)	DIST(FT)	MINLR(DR)	MAXLR(DR)
100.0	38.8	40.8	150.0	42.8	44.8
200.0	45.8	49.8	250.0	48.8	52.8
300.0	52.0	54.0	350.0	54.0	56.0
400.0	56.1	60.1	450.0	58.1	62.1
500.0	53.1	61.1	550.0	54.1	63.1
600.0	62.1	74.1	650.0	61.1	75.1
700.0	72.1	74.1	750.0	68.1	82.1
800.0	70.1	74.1	850.0	74.1	86.1
900.0	71.1	73.1	950.0	73.1	84.1
1000.0	74.1	82.1	1050.0	82.1	90.1
1100.0	84.1	86.1	1150.0	84.1	92.1
1200.0	79.1	84.1	1250.0	84.1	94.1
1300.0	78.1	82.1	1350.0	82.1	90.1
1400.0	80.1	82.1	1450.0	82.1	90.1
1500.0	74.1	79.1	1550.0	79.1	86.1
1600.0	72.1	74.1	1650.0	74.1	82.1
1700.0	81.1	84.1	1750.0	84.1	90.1
1800.0	76.1	77.1	1850.0	84.1	92.1
1900.0	83.1	84.1	1950.0	84.1	90.1
2000.0	82.1	94.1	2050.0	94.1	98.1
2100.0	104.1	112.1	2150.0	112.1	108.1
2200.0	109.1	112.1	2250.0	112.1	101.1
2300.0	100.1	106.1	2350.0	106.1	98.1
2400.0	116.1	132.1	2450.0	132.1	98.1
2500.0	116.1	175.1	2550.0	175.1	98.1
2600.0	106.1	112.1	2650.0	112.1	98.1
2700.0	104.1	116.1	2750.0	116.1	98.1
2800.0	103.1	115.1	2850.0	115.1	98.1
2900.0	104.1	112.1	2950.0	112.1	98.1
3000.0	119.1	116.1	3050.0	116.1	98.1
3100.0	112.1	118.1	3150.0	118.1	98.1
3200.0	116.1	118.1	3250.0	118.1	98.1
3300.0	118.1	111.1	3350.0	111.1	98.1
3400.0	118.1	121.1	3450.0	121.1	98.1
3500.0	111.1	115.1	3550.0	115.1	98.1
3600.0	111.1	119.1	3650.0	119.1	98.1
3700.0	110.1	116.1	3750.0	116.1	98.1
3800.0	105.1	112.1	3850.0	112.1	98.1
3900.0	100.1	110.1	3950.0	110.1	98.1
4000.0	94.1	100.1	4050.0	100.1	98.1
4100.0	96.1	104.1	4150.0	104.1	98.1
4200.0	100.1	104.1	4250.0	104.1	98.1
4300.0	98.1	100.1	4350.0	100.1	98.1
4400.0	100.1	106.1	4450.0	106.1	98.1
4500.0	108.1	115.1	4550.0	115.1	98.1
4600.0	96.1	105.1	4650.0	105.1	98.1
4700.0	106.1	108.1	4750.0	108.1	98.1

Figure 5.2.20 (continued)

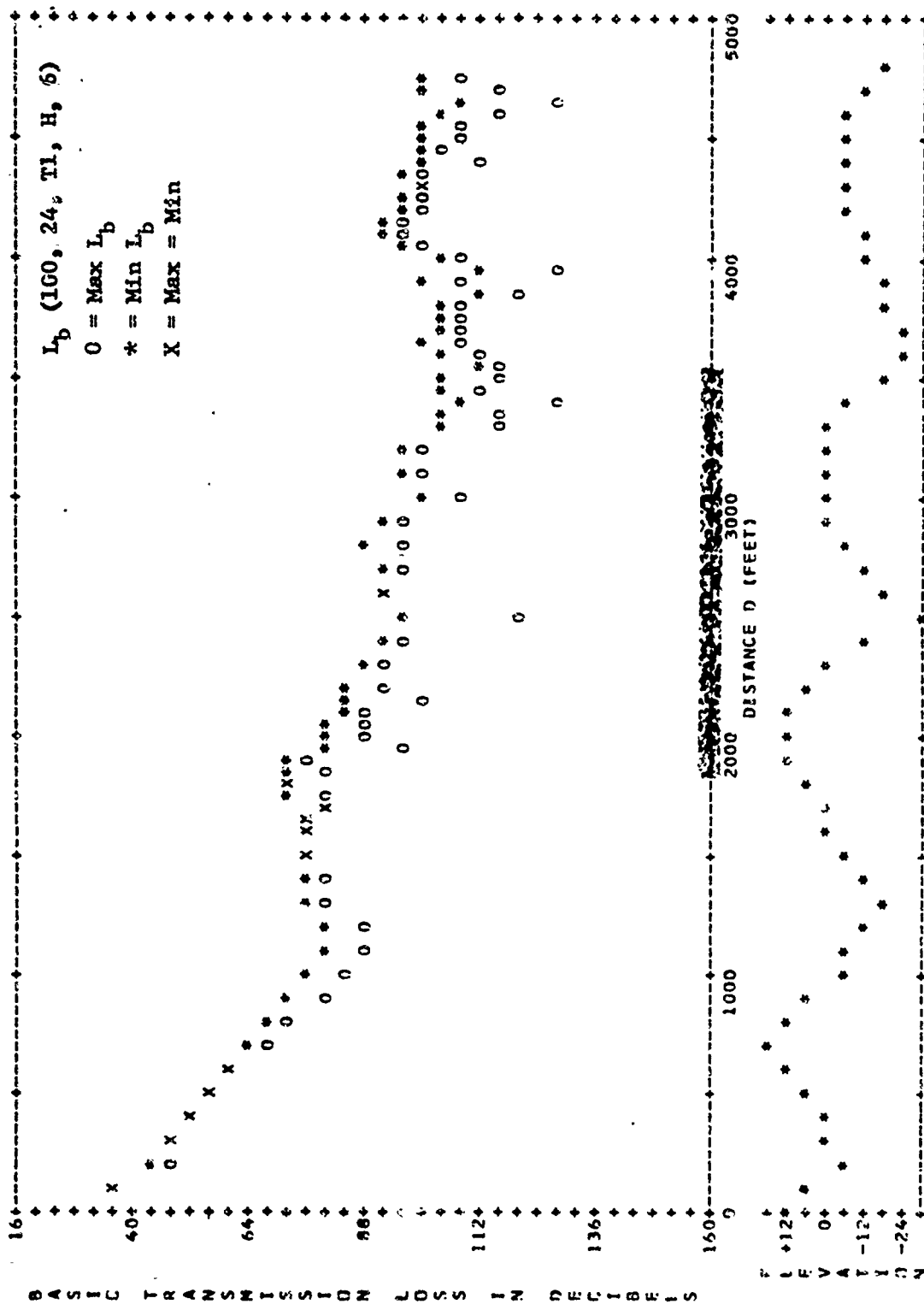


Figure 5.2.21. Basic Transmission Loss and Terrain Elevation vs Distance for Configuration B-O.

MIXED PATH BASIC TRANSMISSION LOSS
WALKING DATA CONFIGURATION R-0, TRANSMITTER T-1

PRFQ.=100MHZ., HT.= 40FT., POL.=H

DIST(FT)	MINLR(DB)	MAXLR(DB)	DIST(FT)	MINLR(DB)	MAXLR(DB)
100.0	36.9	37.9	150.0	44.9	45.9
200.0	45.9	46.9	250.0	49.9	50.9
300.0	47.9	49.9	350.0	52.9	53.9
400.0	50.9	52.9	450.0	55.9	56.9
500.0	55.9	56.9	550.0	61.9	62.9
600.0	58.9	61.9	650.0	66.9	67.9
700.0	64.9	66.9	750.0	71.9	72.9
800.0	67.9	71.9	850.0	74.9	77.9
900.0	73.9	82.9	950.0	78.9	81.9
1000.0	74.9	83.9	1050.0	81.9	84.9
1100.0	80.9	88.9	1150.0	80.9	83.9
1200.0	81.9	89.9	1250.0	80.9	83.9
1300.0	77.9	81.9	1350.0	77.9	80.9
1400.0	76.9	80.9	1450.0	74.9	77.9
1500.0	75.9	77.9	1550.0	73.9	76.9
1600.0	74.9	77.9	1650.0	73.9	76.9
1700.0	78.9	81.9	1750.0	73.9	76.9
1800.0	71.9	73.9	1850.0	73.9	76.9
1900.0	71.9	76.9	1950.0	72.9	75.9
2000.0	78.9	80.9	2050.0	72.9	75.9
2100.0	84.9	87.9	2150.0	72.9	75.9
2200.0	85.9	91.9	2250.0	72.9	75.9
2300.0	87.9	92.9	2350.0	72.9	75.9
2400.0	93.9	97.9	2450.0	72.9	75.9
2500.0	95.9	118.9	2550.0	72.9	75.9
2600.0	90.9	92.9	2650.0	72.9	75.9
2700.0	91.9	96.9	2750.0	72.9	75.9
2800.0	88.9	94.9	2850.0	72.9	75.9
2900.0	92.9	95.9	2950.0	72.9	75.9
3000.0	100.9	106.9	3050.0	72.9	75.9
3100.0	95.9	98.9	3150.0	72.9	75.9
3200.0	95.9	98.9	3250.0	72.9	75.9
3300.0	103.9	116.9	3350.0	72.9	75.9
3400.0	107.9	126.9	3450.0	72.9	75.9
3500.0	102.9	117.9	3550.0	72.9	75.9
3600.0	104.9	110.9	3650.0	72.9	75.9
3700.0	104.9	104.9	3750.0	72.9	75.9
3800.0	104.9	107.9	3850.0	72.9	75.9
3900.0	101.9	106.9	3950.0	72.9	75.9
4000.0	104.9	108.9	4050.0	72.9	75.9
4100.0	93.9	97.9	4150.0	72.9	75.9
4200.0	94.9	98.9	4250.0	72.9	75.9
4300.0	98.9	101.9	4350.0	72.9	75.9
4400.0	99.9	112.9	4450.0	72.9	75.9
4500.0	100.9	106.9	4550.0	72.9	75.9
4600.0	102.9	116.9	4650.0	72.9	75.9
4700.0	100.9	114.9	4750.0	72.9	75.9

Figure 5.2.21 (continued)

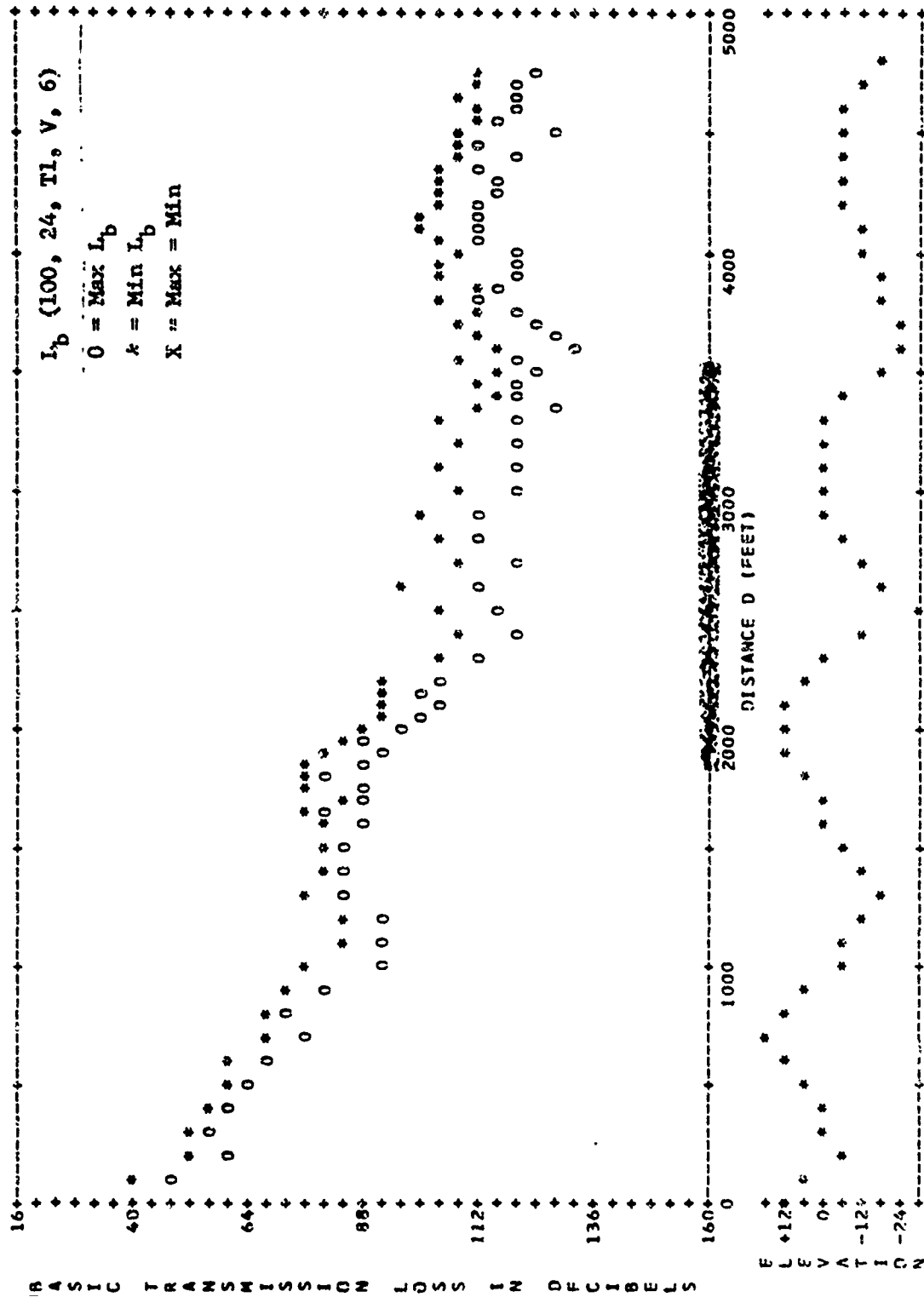


Figure 5.2.22. Basic Transmission Loss and Terrain Elevation vs Distance for Configuration B-0.

MIXED PATH BASIC TRANSMISSION LOSS
WALKING DATA CONFIGURATION R-O, TRANSMITTER T-1

PRFQ.=100MHZ, MT.= 40FT., PUL.=V

DIST(FT)	MINLR(DB)	MAXLR(DB)	DIST(FT)	MINLR(DB)	MAXLR(DB)
100.0	42.0	47.0	150.0	*****	*****
200.0	52.0	61.0	250.0	*****	*****
300.0	53.2	56.2	350.0	*****	*****
400.0	57.3	61.3	450.0	*****	*****
500.0	59.3	63.3	550.0	*****	*****
600.0	61.3	66.3	650.0	*****	*****
700.0	66.3	76.3	750.0	*****	*****
800.0	68.3	72.3	850.0	*****	*****
900.0	71.4	81.4	950.0	*****	*****
1000.0	75.4	91.4	1050.0	*****	*****
1100.0	85.4	91.4	1150.0	*****	*****
1200.0	85.4	93.4	1250.0	*****	*****
1300.0	77.4	84.4	1350.0	*****	*****
1400.0	79.4	83.4	1450.0	*****	*****
1500.0	79.4	84.4	1550.0	*****	*****
1600.0	79.4	88.4	1650.0	75.4	78.4
1700.0	82.4	88.4	1750.0	77.4	83.4
1800.0	76.4	80.4	1850.0	84.4	86.4
1900.0	79.4	91.4	1950.0	93.4	88.4
2000.0	86.4	96.4	2050.0	91.4	101.4
2100.0	93.4	105.4	2150.0	*****	95.4
2200.0	92.4	104.4	2250.0	*****	*****
2300.0	104.4	111.4	2350.0	*****	*****
2400.0	107.4	119.4	2450.0	*****	*****
2500.0	105.4	115.4	2550.0	*****	*****
2600.0	97.4	111.4	2650.0	*****	*****
2700.0	107.4	121.4	2750.0	*****	*****
2800.0	102.4	110.4	2850.0	*****	*****
2900.0	101.4	111.4	2950.0	*****	*****
3000.0	109.4	121.4	3050.0	*****	*****
3100.0	104.4	119.4	3150.0	*****	*****
3200.0	103.4	119.4	3250.0	*****	*****
3300.0	105.4	121.4	3350.0	112.4	129.4
3400.0	114.4	119.4	3450.0	112.4	118.4
3500.0	116.4	123.4	3550.0	106.4	121.4
3600.0	114.4	131.4	3650.0	111.4	126.4
3700.0	106.4	124.4	3750.0	110.4	121.4
3800.0	105.4	117.4	3850.0	110.4	114.4
3900.0	104.4	120.4	3950.0	105.4	119.4
4000.0	107.4	121.4	4050.0	102.4	120.4
4100.0	99.4	111.4	4150.0	100.4	111.4
4200.0	102.4	110.4	4250.0	104.4	115.4
4300.0	104.4	114.4	4350.0	105.4	111.4
4400.0	103.4	118.4	4450.0	103.4	113.4
4500.0	110.4	128.4	4550.0	110.4	114.4
4600.0	112.4	120.4	4650.0	104.4	119.4
4700.0		120.4	4750.0	111.4	123.4

Figure 5.2.22 (continued)

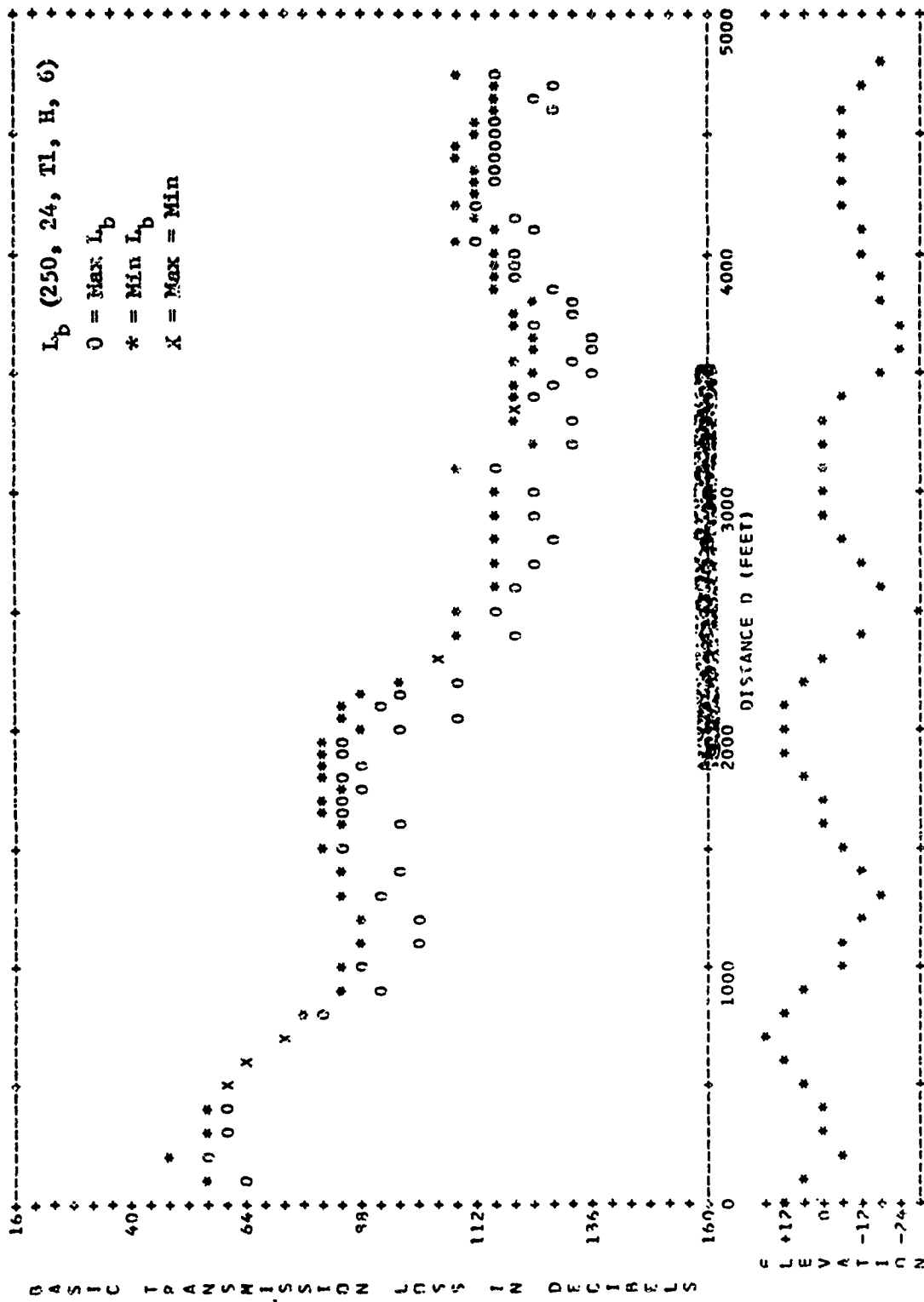


Figure 5.2.23. Basic Transmission Loss and Terrain Elevation vs Distance for Configuration B-0.

MIXED PATH BASIC TRANSMISSION LOSS
WALKING DATA CONFIGURATION R-0, TRANSMITTER F-1

FREQ.=250MHZ., HT.= 40FT., POL.=H

DIST(FT)	MINLR(DB)	MAXLR(DB)	DIST(FT)	MINLR(DB)	MAXLR(DB)
100.0	54.5	64.5	150.0	*****	*****
200.0	48.5	54.5	250.0	*****	*****
300.0	56.5	58.5	350.0	*****	*****
400.0	56.5	58.5	450.0	*****	*****
500.0	54.5	54.5	550.0	*****	*****
600.0	62.5	64.5	650.0	*****	*****
700.0	70.5	72.5	750.0	*****	*****
800.0	76.5	78.5	850.0	*****	*****
900.0	82.5	92.5	950.0	*****	*****
1000.0	84.5	88.5	1050.0	*****	*****
1100.0	84.5	98.5	1150.0	*****	*****
1200.0	84.5	101.5	1250.0	*****	*****
1300.0	83.5	91.5	1350.0	*****	*****
1400.0	84.5	94.5	1450.0	*****	*****
1500.0	79.5	84.5	1550.0	*****	*****
1600.0	82.5	94.5	1650.0	80.5	85.5
1700.0	78.5	85.5	1750.0	83.5	88.5
1800.0	80.5	82.5	1850.0	80.5	86.5
1900.0	81.5	84.5	1950.0	81.5	84.5
2000.0	88.5	96.5	2050.0	84.5	108.5
2100.0	85.5	92.5	2150.0	88.5	96.5
2200.0	96.5	106.5	2250.0	*****	*****
2300.0	102.5	104.5	2350.0	*****	*****
2400.0	106.5	114.5	2450.0	*****	*****
2500.0	106.5	114.5	2550.0	*****	*****
2600.0	114.5	120.5	2650.0	*****	*****
2700.0	114.5	122.5	2750.0	*****	*****
2800.0	117.5	127.5	2850.0	*****	*****
2900.0	114.5	124.5	2950.0	*****	*****
3000.0	114.5	123.5	3050.0	*****	*****
3100.0	108.5	116.5	3150.0	*****	*****
3200.0	122.5	132.5	3250.0	*****	*****
3300.0	119.5	130.5	3350.0	118.5	121.5
3400.0	119.5	124.5	3450.0	120.5	127.5
3500.0	122.5	134.5	3550.0	123.5	132.5
3600.0	123.5	134.5	3650.0	124.5	134.5
3700.0	121.5	124.5	3750.0	119.5	130.5
3800.0	122.5	132.5	3850.0	116.5	128.5
3900.0	114.5	120.5	3950.0	114.5	119.5
4000.0	114.5	120.5	4050.0	108.5	111.5
4100.0	116.5	123.5	4150.0	112.5	118.5
4200.0	104.5	111.5	4250.0	112.5	*****
4300.0	110.5	114.5	4350.0	110.5	114.5
4400.0	109.5	116.5	4450.0	109.5	116.5
4500.0	111.5	116.5	4550.0	110.5	115.5
4600.0	114.5	126.5	4650.0	114.5	124.5
4700.0	116.5	129.5	4750.0	106.5	114.5

Figure 5.2.23 (continued)

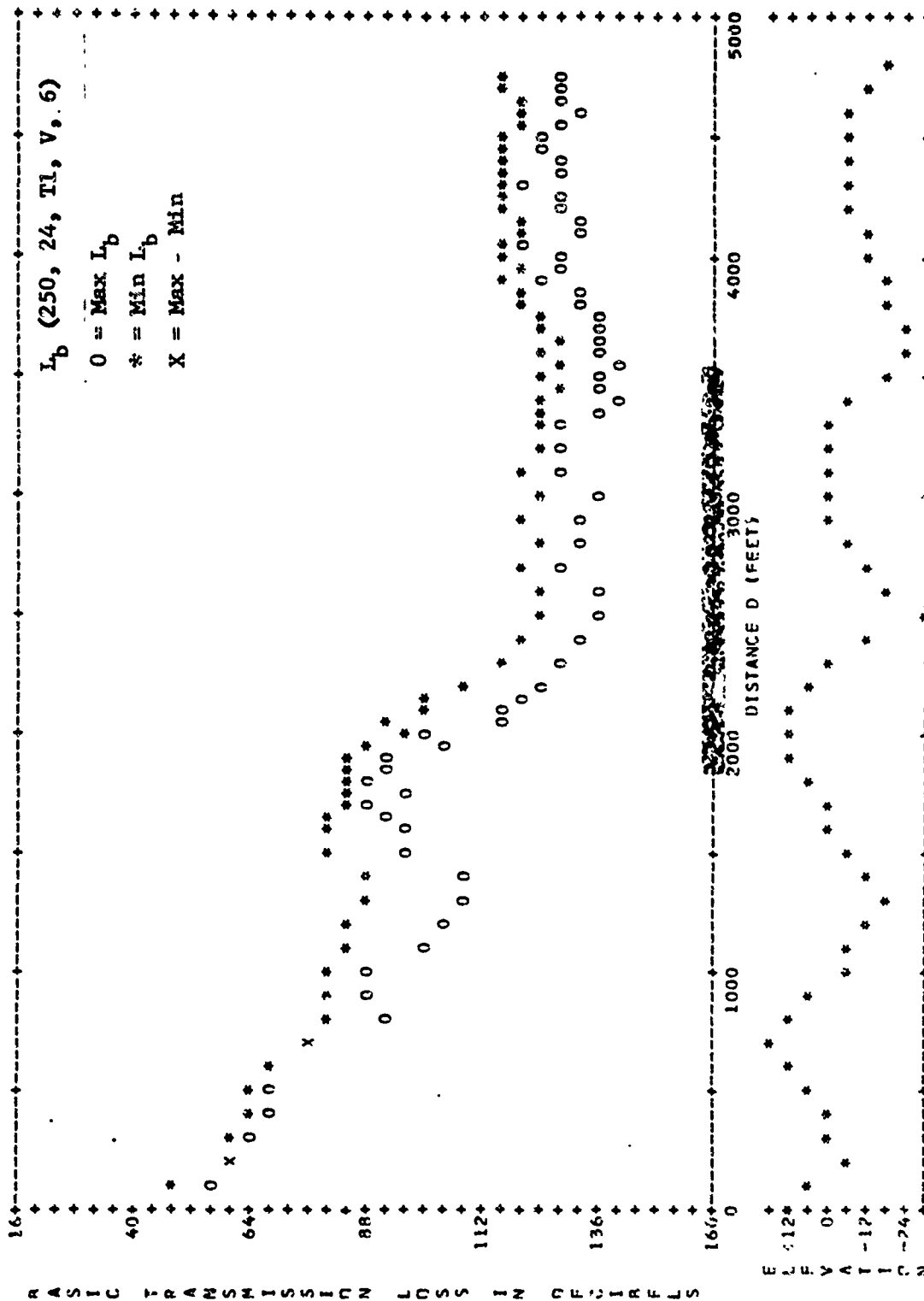


Figure 5.2.24. Basic Transmission Loss and Terrain Elevation vs Distance for Configuration B-0.

MIXED PATH BASIC TRANSMISSION LOSS
WALKING DATA CONFIGURATION 0-0, TRANSMITTER T-1

FREQ.=250MHZ., HT.= 40FT., PUL.=V

DIST(FT)	MINLR(DB)	MAXLR(DB)	DIST(FT)	MINLR(DB)	MAXLR(DB)
100.0	49.6	55.6	150.0	*****	*****
200.0	58.6	60.6	250.0	*****	*****
300.0	60.8	62.8	350.0	*****	*****
400.0	62.8	67.8	450.0	*****	*****
500.0	64.9	66.9	550.0	*****	*****
600.0	67.9	*****	650.0	*****	*****
700.0	74.9	76.9	750.0	*****	*****
800.0	80.9	92.0	850.0	*****	*****
900.0	80.9	86.9	950.0	*****	*****
1000.0	78.9	88.9	1050.0	*****	*****
1100.0	85.9	98.9	1150.0	*****	*****
1200.0	83.9	104.9	1250.0	*****	*****
1300.0	87.9	106.9	1350.0	*****	*****
1400.0	86.9	109.9	1450.0	*****	*****
1500.0	79.9	94.9	1550.0	*****	*****
1600.0	79.9	95.0	1650.0	81.9	91.9
1700.0	82.9	88.9	1750.0	83.9	96.9
1800.0	82.9	88.9	1850.0	82.9	90.9
1900.0	84.9	92.9	1950.0	89.9	104.9
2000.0	94.9	100.9	2050.0	93.9	114.9
2100.0	98.9	114.9	2150.0	99.9	116.9
2200.0	108.9	124.9	2250.0	*****	*****
2300.0	114.9	126.9	2350.0	*****	*****
2400.0	119.9	132.9	2450.0	*****	*****
2500.0	125.9	134.9	2550.0	*****	*****
2600.0	122.9	134.9	2650.0	*****	*****
2700.0	118.9	126.9	2750.0	*****	*****
2800.0	122.9	130.9	2850.0	*****	*****
2900.0	118.9	134.9	2950.0	*****	*****
3000.0	122.9	134.9	3050.0	*****	*****
3100.0	120.9	128.9	3150.0	*****	*****
3200.0	124.9	127.9	3250.0	*****	*****
3300.0	127.9	127.9	3350.0	*****	*****
3400.0	124.9	138.9	3450.0	124.9	134.9
3500.0	125.9	134.9	3550.0	127.9	136.9
3600.0	122.9	124.9	3650.0	128.9	138.9
3700.0	122.9	134.9	3750.0	125.9	134.9
3800.0	119.9	132.9	3850.0	121.9	132.9
3900.0	117.9	125.9	3950.0	118.9	128.9
4000.0	116.9	127.9	4050.0	114.9	111.9
4100.0	118.9	131.9	4150.0	119.9	132.9
4200.0	116.9	124.9	4250.0	116.9	128.9
4300.0	116.9	120.9	4350.0	114.9	127.9
4400.0	114.9	126.9	4450.0	114.9	124.9
4500.0	114.9	122.9	4550.0	120.9	129.9
4600.0	114.9	130.9	4650.0	114.9	129.9
4700.0	117.9	127.9	4750.0	114.9	129.9

Figure 5.2.24 (continued)

8	15	21	28	RECEIVE HEIGHT (FEET)								CONF	TRANS-REC	SYM	DIST (Mi)		
				34	40	45	50	55	60	65	70					75	80
94	89	87	85	82	81	79	78	77	76	76	75	75	74	80	Y1-R1	0	0.899
90	85	82	81	80	79	79	78	78	78	77	77	77	77	80	Y1-R2	*	0.710
84	80	76	74	71	70	69	68	66	65	64	63	63	62	80	Y1-R3	.	0.407

L_p (25, 40, T1, H, H_R)

Receive Height (Feet)	Y1-R1 (Lp)	Y1-R2 (Lp)	Y1-R3 (Lp)
34	82	80	71
40	81	79	70
45	79	79	69
50	78	78	68
55	77	78	66
60	76	78	65
65	76	77	64
70	75	77	63
75	75	77	63
80	74	77	62

Figure 5.2.25 Basic Transmission Loss vs Receive Antenna Height for Configuration B-0

DIST (Mi)	CONF	TRANS-REC	-SYM	RECEIVE HEIGHT (FEET)															
				8	15	23	28	34	40	45	50	55	60	65	70	75	80		
93	91	93	97	94	91	87	87	88	87	86	86	86	86	84	80	T1-R1	0	0.899	
106	111	114	111	107	104	102	101	101	100	99	99	97	96	96	80	T1-R2	*	0.710	
103	99	99	93	92	89	84	81	78	77	77	77	76	74	72	80	T1-R3	.	0.407	

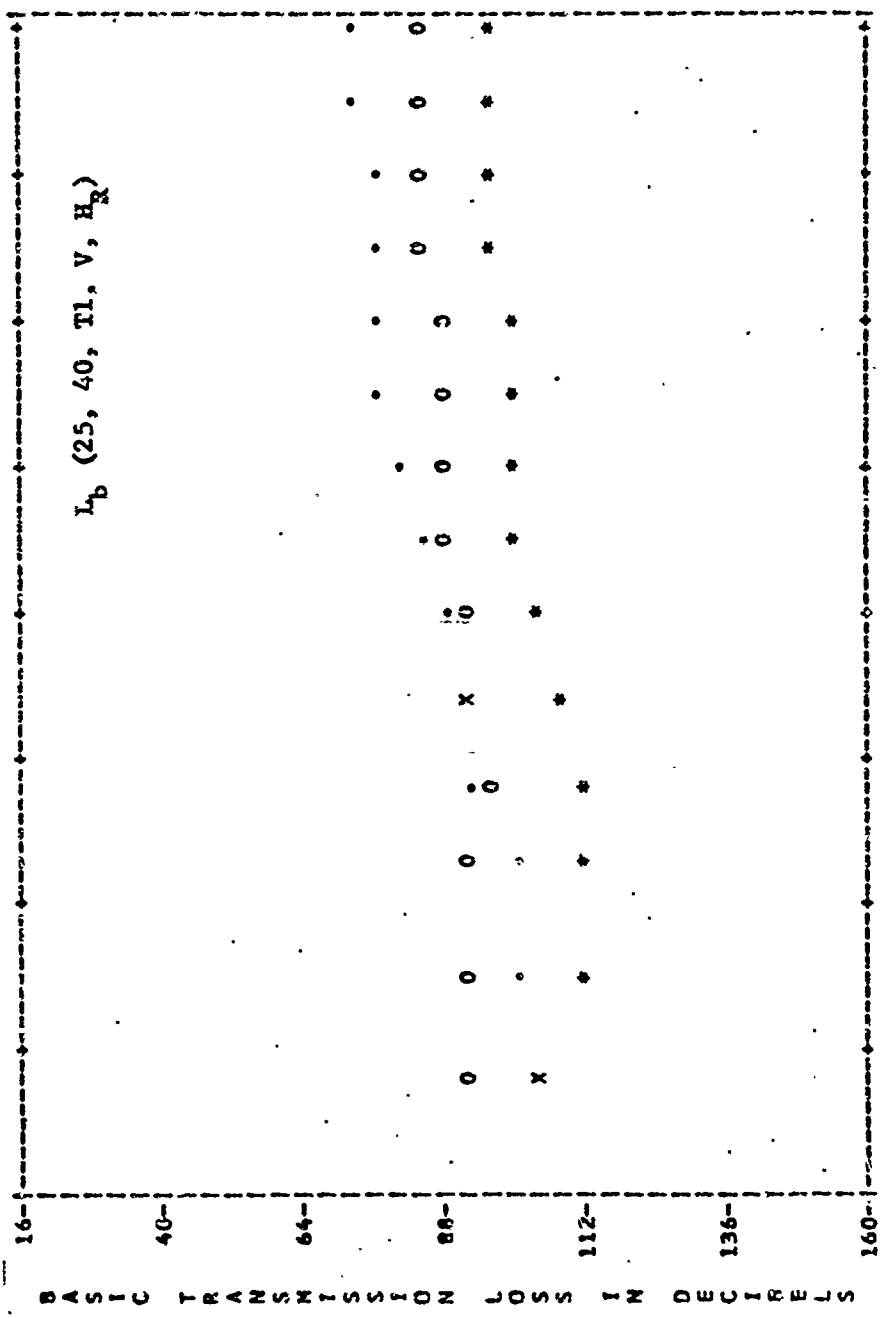


Figure 5.2.26 Basic Transmission Loss vs Receive Antenna Height for Configuration B-0

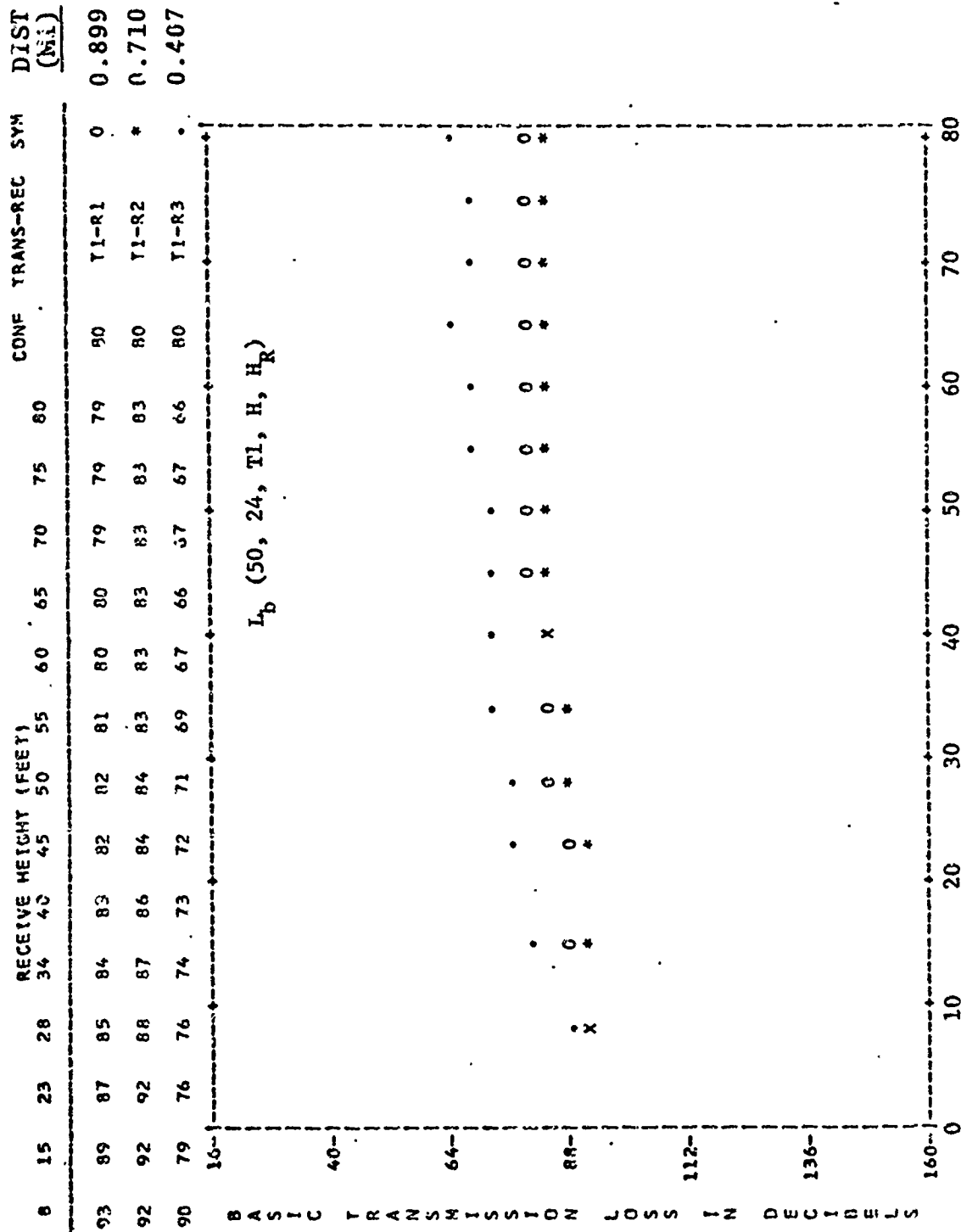


Figure 5.2.27 Basic Transmission Loss vs Receive Antenna Height for Configuration B-0

R	RECEIVE HEIGHT (FEET)										CONF	TRANS-REC	SYM	DIST (Mi)
	15	23	28	34	40	45	50	55	60	65	70	75	80	
101	97	93	92	91	89	88	87	88	89	88	87	87	88	0 0.899
100	98	96	95	95	95	95	95	94	93	92	91	91	91	* 0.710
95	91	90	89	89	89	88	87	86	85	84	81	77	74	0.407

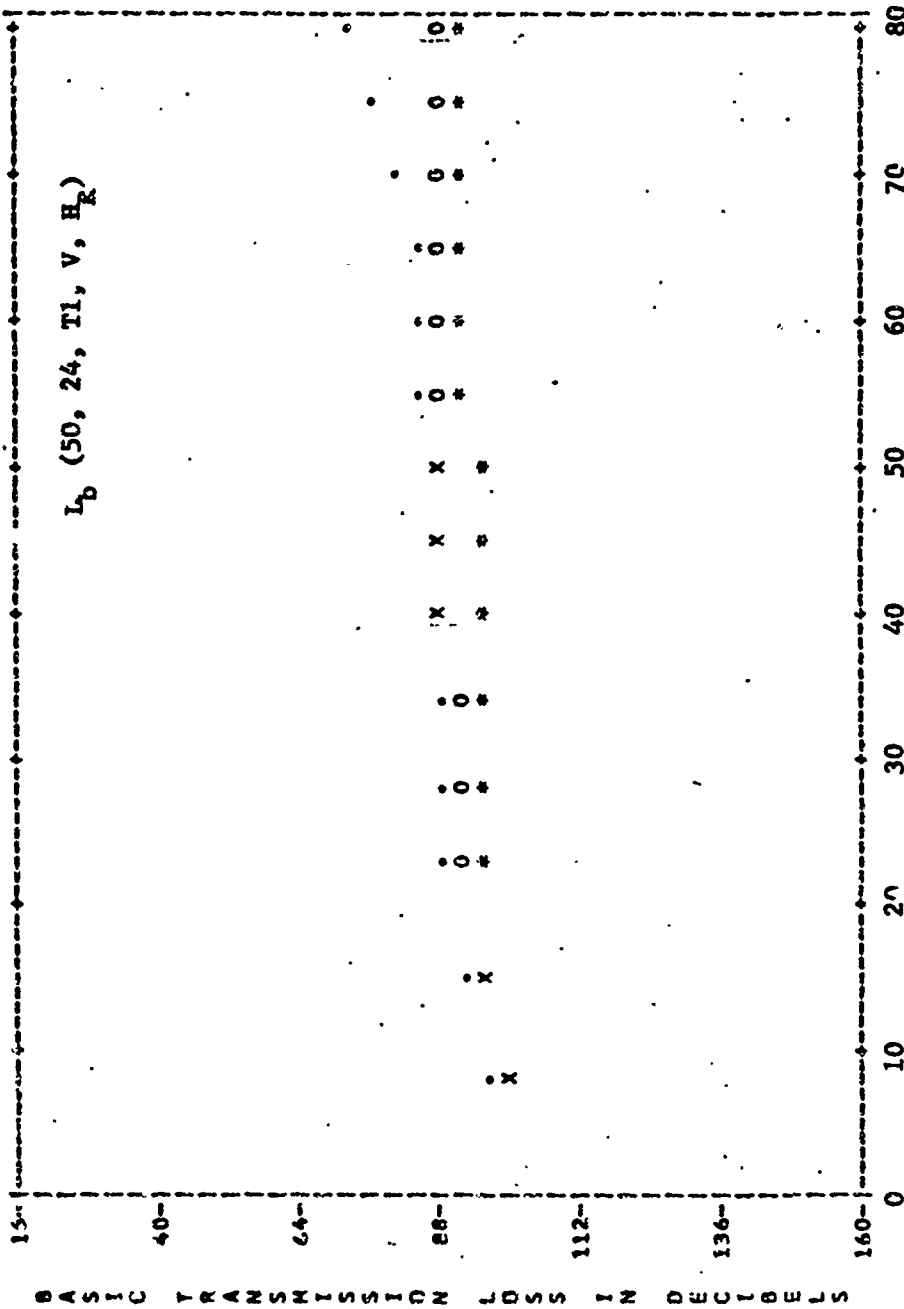


Figure 5.2.28 Basic Transm. Loss vs Receive Antenna Height for Configuration B-0

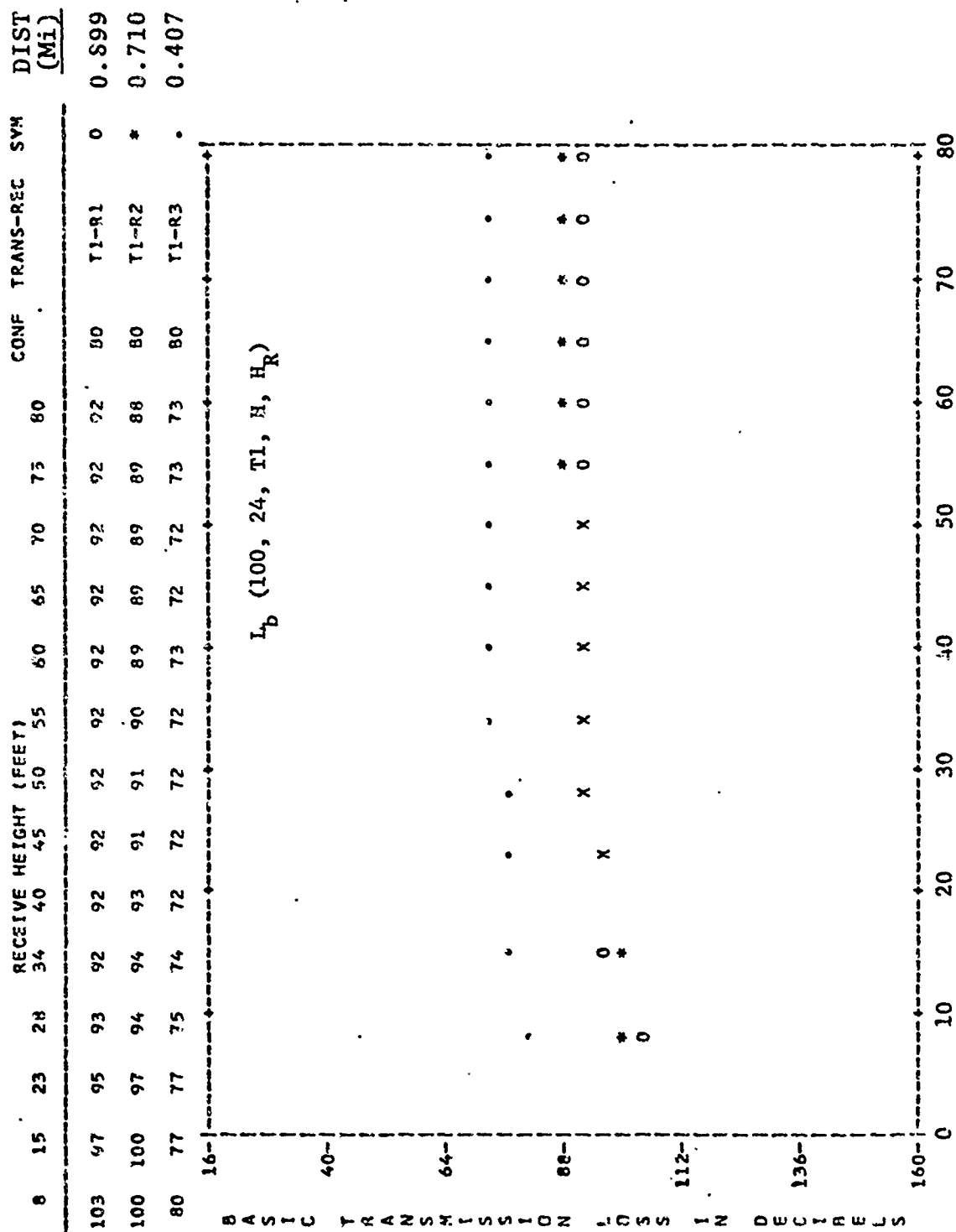


Figure 5.2.29 Basic Transmission Loss vs Receive Antenna Height for Configuration B-0

		RECEIVE HEIGHT (FEET)										CONF		TRANS-REC	SYM	DIST (Mi)
8	15	23	28	34	40	45	50	55	60	65	70	75	80			
106	102	101	99	96	94	94	94	94	95	96	100	103	101	80	T1-R1	0 0.899
114	115	117	110	105	104	102	101	102	102	103	102	99	97	80	T1-R2.	* 0.710
101	99	97	95	93	88	94	98	96	90	84	79	74	74	80	T1-R3	• 0.407

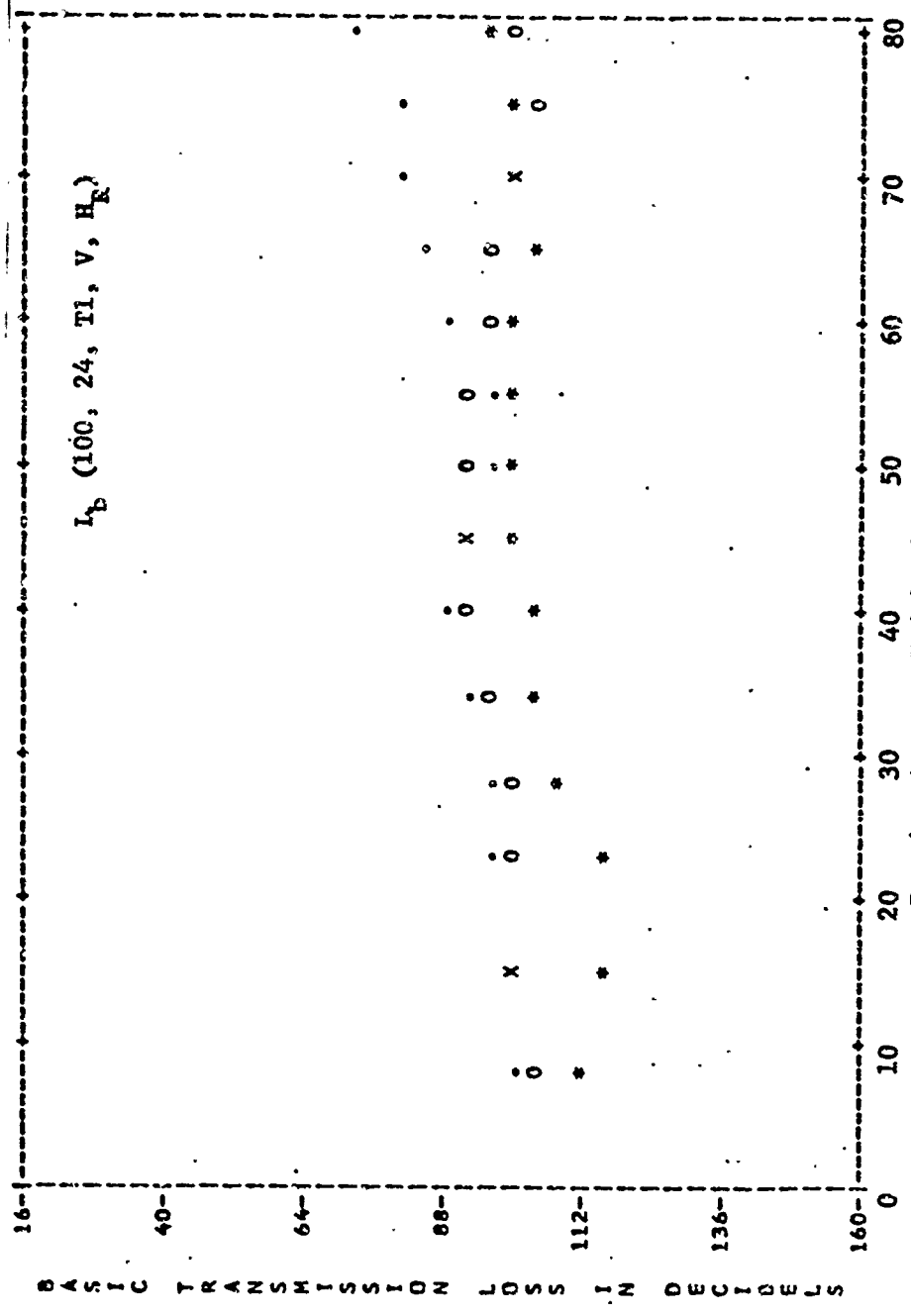


Figure 5.2.30 Basic Transmission Loss vs Receive Antenna Height for Configuration B-0

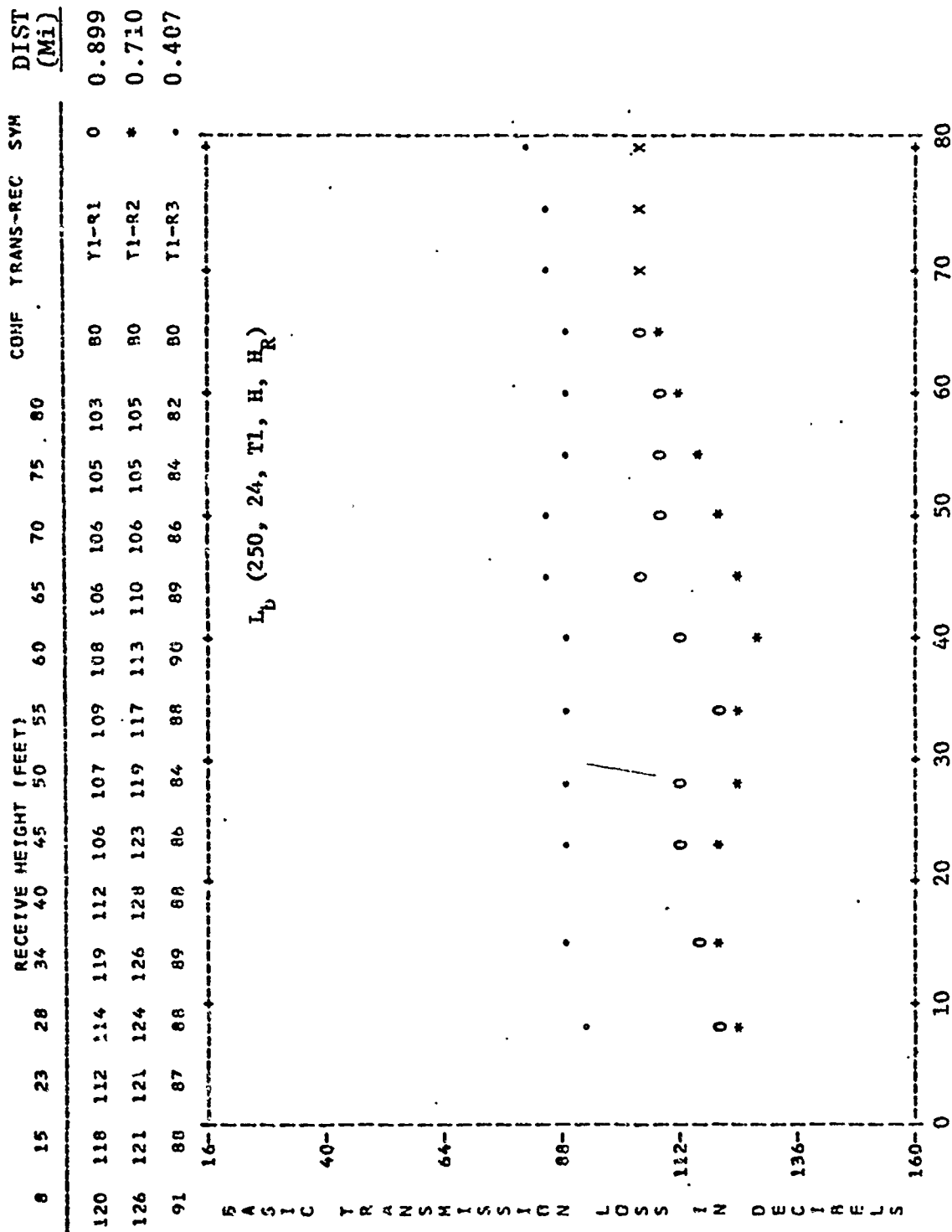


Figure 5.2.31 Basic Transmission Loss vs Receive Antenna Height for Configuration R-0

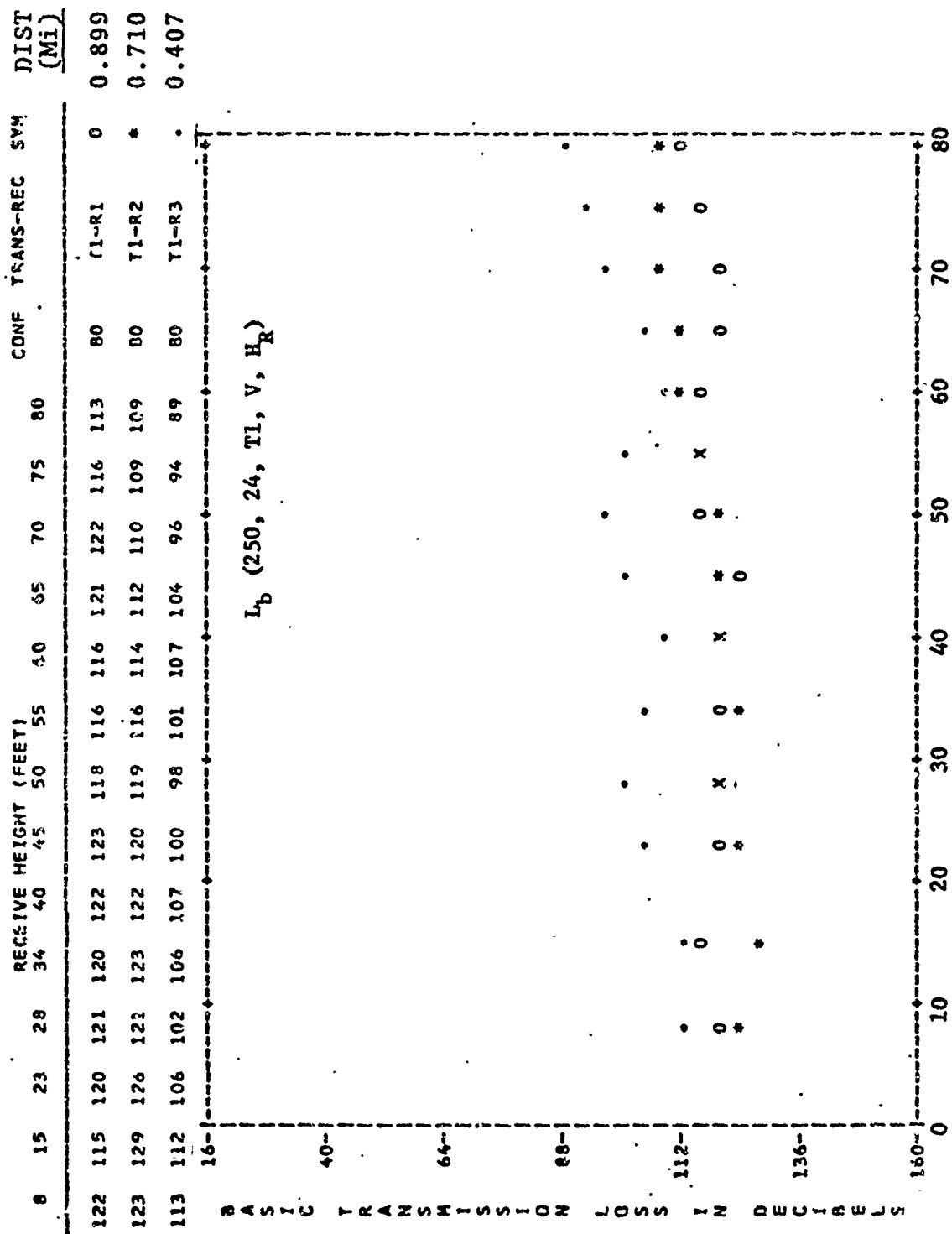


Figure 5.2.32 Basic Transmission Loss vs Receive Antenna Height for Configuration B-0

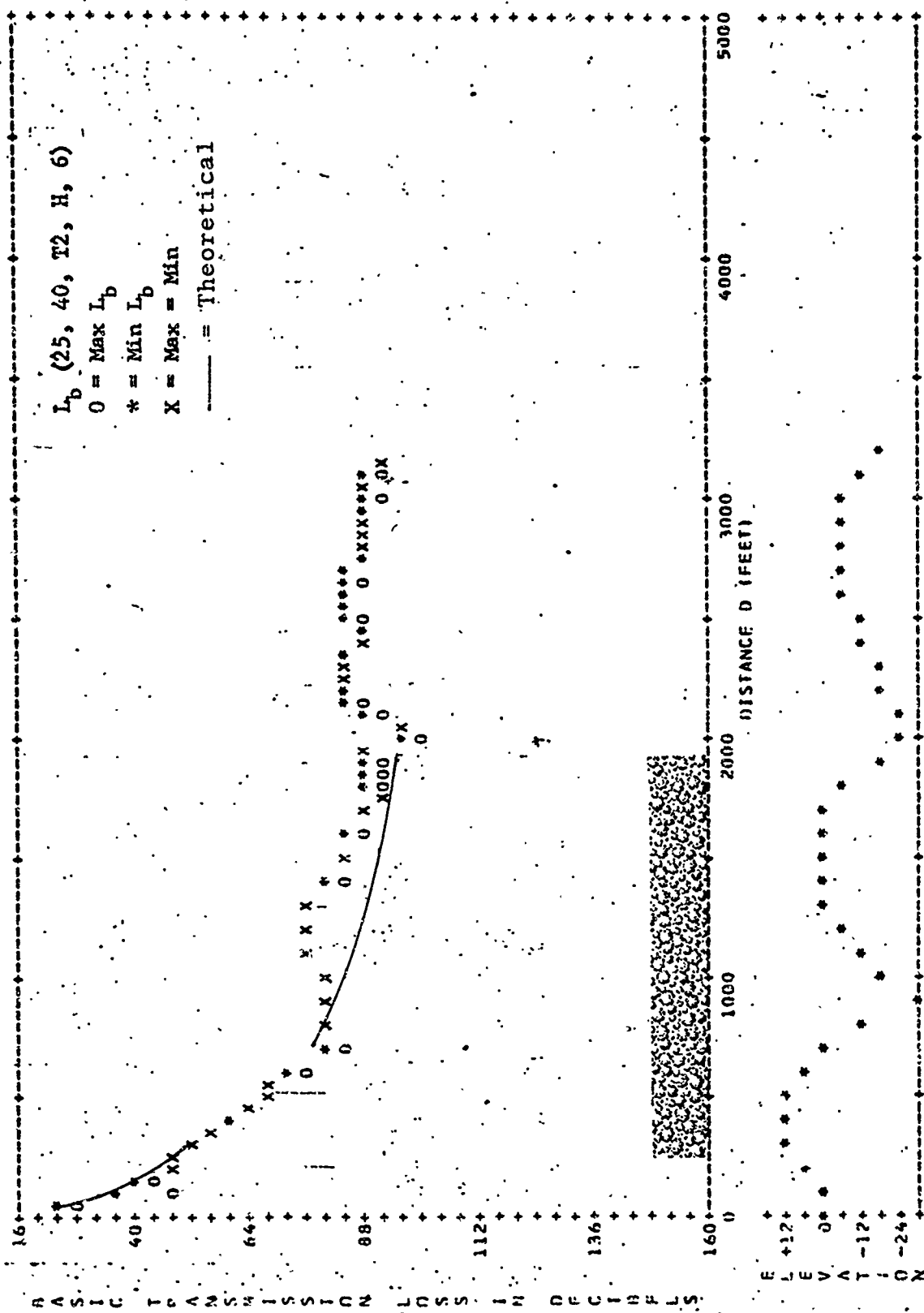


Figure 5.2.33 Basic Transmission Loss and Terrain Elevation vs Distance for Configuration B-0

MIXED PATH BASIC TRANSMISSION LOSS
WALKING DATA CONFIGURATION R-0, TRANSMITTER T-2

FREQ.= 25MHZ., HT.= 40FT., PDL.=H

DIST(FT.)	MINL(0B)	MAXL(0B)	DIST(FT)	MINL(0B)	MAXL(0B)
50.0	25.7	27.7	100.0	36.9	48.9
150.0	41.1	42.1	200.0	46.2	47.2
250.0	48.2	49.2	300.0	50.3	52.3
350.0	55.3	56.3	400.0	60.3	60.3
450.0	63.3	64.3	500.0	67.3	68.3
550.0	67.3	68.3	600.0	70.3	77.3
650.0	67.3	68.3	700.0	80.3	82.3
750.0	67.3	68.3	800.0	80.3	81.3
850.0	67.3	68.3	900.0	78.3	80.3
950.0	67.3	68.3	1000.0	78.3	79.3
1050.0	67.3	68.3	1100.0	75.3	76.3
1150.0	67.3	68.3	1200.0	76.3	77.3
1250.0	67.3	68.3	1300.0	76.3	77.3
1350.0	67.3	68.3	1400.0	81.3	85.3
1450.0	67.3	68.3	1500.0	87.3	83.3
1550.0	67.3	68.3	1600.0	83.3	88.3
1650.0	67.3	68.3	1700.0	87.3	88.3
1750.0	67.3	68.3	1800.0	87.3	91.3
1850.0	67.3	68.3	1900.0	89.3	90.3
1950.0	67.3	68.3	2000.0	95.3	99.3
2050.0	67.3	68.3	2100.0	89.3	90.3
2150.0	67.3	68.3	2200.0	84.3	85.3
2250.0	67.3	68.3	2300.0	84.3	87.3
2350.0	67.3	68.3	2400.0	86.3	86.3
2450.0	67.3	68.3	2500.0	85.3	86.3
2550.0	67.3	68.3	2600.0	85.3	85.3
2650.0	67.3	68.3	2700.0	85.3	85.3
2750.0	67.3	68.3	2800.0	86.3	87.3
2850.0	67.3	68.3	2900.0	87.3	87.3
2950.0	67.3	68.3	3000.0	87.3	91.3
3050.0	67.3	68.3	3100.0	88.3	95.3
3150.0	67.3	68.3	3200.0	88.3	95.3

Figure 5.2.33 Continued

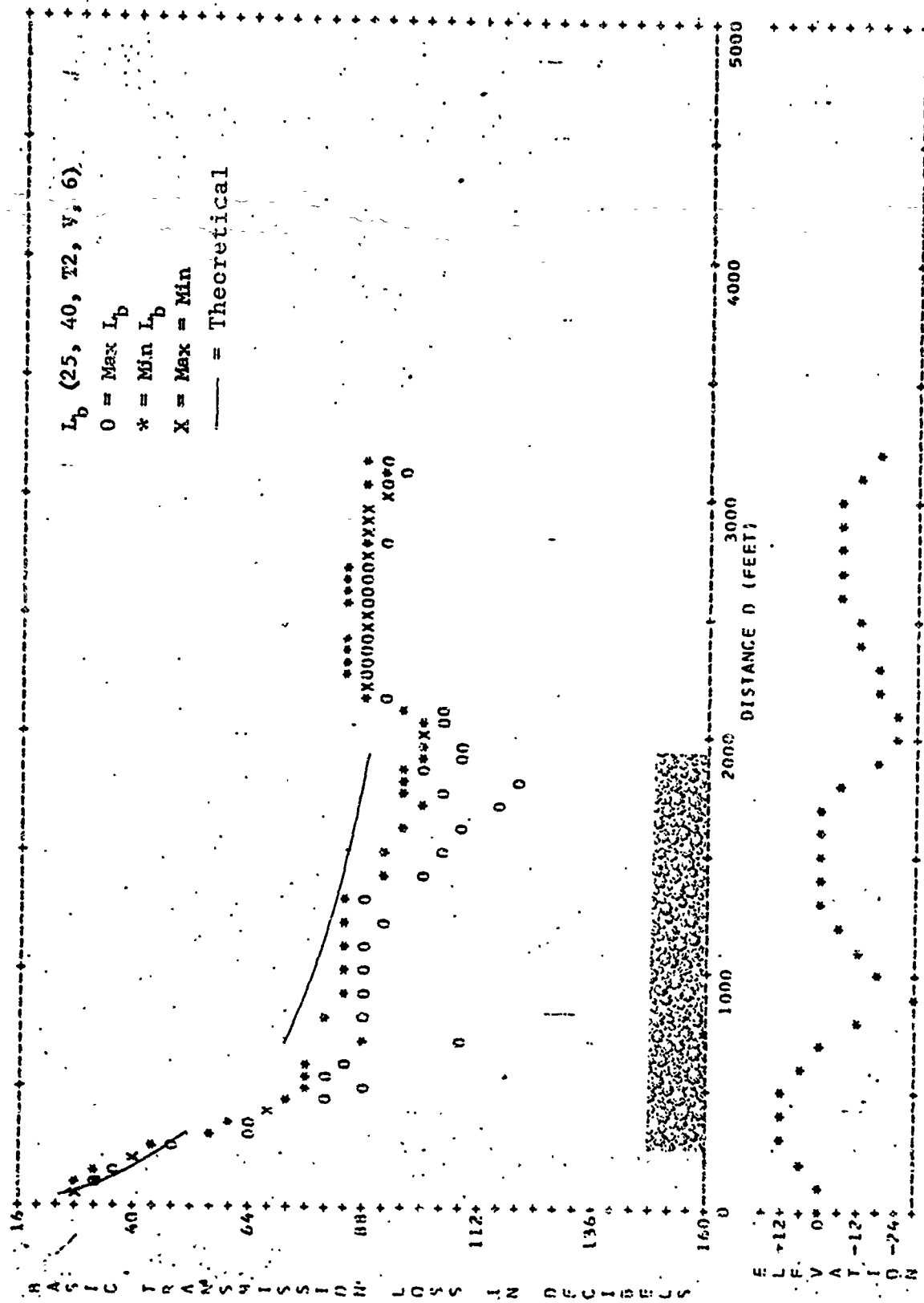
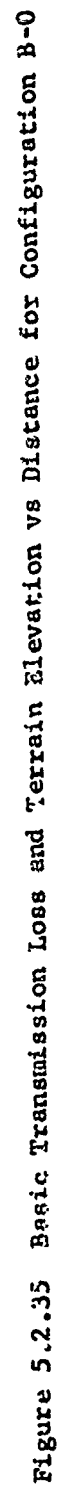


Figure 5.2.34 Basic Transmission Loss and Terrain Elevation vs Distance for Configuration B-0

MIXED PATH BASIC TRANSMISSION LOSS
WALKING DATA CONFIGURATION D-O, TRANSMITTER T-2
FREQ.= 25MHZ., HT.= 40FT., PRL.=V

DIST(FT)	MINLB(DBI)	MAXLB(DBI)	DIST(FT)	MINLB(DBI)	MAXLB(DBI)
50.0	27.0	28.0	100.0	28.0	30.0
150.0	33.0	36.0	200.0	38.1	43.1
250.0	43.2	46.2	300.0	56.2	63.2
350.0	61.3	64.3	400.0	67.3	69.3
450.0	73.3	79.3	500.0	77.3	87.3
550.0	74.3	78.3	600.0	76.3	85.3
650.0	*****	*****	700.0	87.3	109.3
750.0	*****	*****	800.0	80.3	89.3
850.0	*****	*****	900.0	83.3	86.3
950.0	*****	*****	1000.0	81.3	89.3
1050.0	*****	*****	1100.0	81.3	87.3
1150.0	*****	*****	1200.0	87.3	92.3
1250.0	*****	*****	1300.0	83.3	89.3
1350.0	*****	*****	1400.0	90.3	101.3
1450.0	*****	*****	1500.0	93.3	103.3
1550.0	*****	*****	1600.0	96.3	107.3
1650.0	*****	*****	1700.0	98.3	117.3
1750.0	95.3	103.3	1800.0	96.3	120.3
1850.0	95.3	99.3	1900.0	100.3	107.3
1950.0	100.3	108.3	2000.0	99.3	100.3
2050.0	101.3	105.3	2100.0	94.3	103.3
2150.0	89.3	90.3	2200.0	88.3	84.3
2250.0	85.3	88.3	2300.0	85.3	87.3
2350.0	81.3	86.3	2400.0	84.3	88.3
2450.0	87.3	88.3	2500.0	89.3	89.3
2550.0	85.3	87.3	2600.0	84.3	89.3
2650.0	84.3	86.3	2700.0	85.3	89.3
2750.0	88.3	89.3	2800.0	87.3	88.3
2850.0	87.3	88.3	2900.0	87.3	88.3
2950.0	88.3	88.3	3000.0	90.3	91.3
3050.0	89.3	91.3	3100.0	93.3	96.3
3150.0	89.3	93.3	3200.0	*****	*****

Figure 5.2.34 Continued



MIXED PATH BASIC TRANSMISSION LOSS
WALKING DATA CONFIGURATION A-Q, TRANSMITTER T-2

FREQ. = 50MHZ., HT. = 40FT., PCL. = H

DIST(FT)	MINLR(DB)	MAXLR(DB)	DIST(FT)	MINLR(DB)	MAXLR(DB)
50.0	30.4	32.4	100.0	38.4	40.4
150.0	43.4	45.4	200.0	49.4	51.4
250.0	52.4	54.4	300.0	54.4	56.4
350.0	58.4	60.4	400.0	59.4	61.4
450.0	62.4	64.4	500.0	63.4	65.4
550.0	69.4	71.4	600.0	70.4	72.4
650.0	74.4	76.4	700.0	75.4	77.4
750.0	79.4	81.4	800.0	81.4	83.4
850.0	84.4	86.4	900.0	85.4	87.4
950.0	89.4	91.4	1000.0	89.4	91.4
1050.0	94.4	96.4	1100.0	93.4	95.4
1150.0	99.4	101.4	1200.0	98.4	100.4
1250.0	104.4	106.4	1300.0	103.4	105.4
1350.0	109.4	111.4	1400.0	108.4	110.4
1450.0	114.4	116.4	1500.0	113.4	115.4
1550.0	119.4	121.4	1600.0	118.4	120.4
1650.0	124.4	126.4	1700.0	123.4	125.4
1750.0	129.4	131.4	1800.0	128.4	130.4
1850.0	134.4	136.4	1900.0	133.4	135.4
1950.0	139.4	141.4	2000.0	138.4	140.4
2050.0	144.4	146.4	2100.0	143.4	145.4
2150.0	149.4	151.4	2200.0	148.4	150.4
2250.0	154.4	156.4	2300.0	153.4	155.4
2350.0	159.4	161.4	2400.0	158.4	160.4
2450.0	164.4	166.4	2500.0	163.4	165.4
2550.0	169.4	171.4	2600.0	168.4	170.4
2650.0	174.4	176.4	2700.0	173.4	175.4
2750.0	179.4	181.4	2800.0	178.4	180.4
2850.0	184.4	186.4	2900.0	183.4	185.4
2950.0	189.4	191.4	3000.0	188.4	190.4
3050.0	194.4	196.4	3100.0	193.4	195.4
3150.0	199.4	201.4	3200.0	198.4	200.4

Figure 5.2.35 Continued

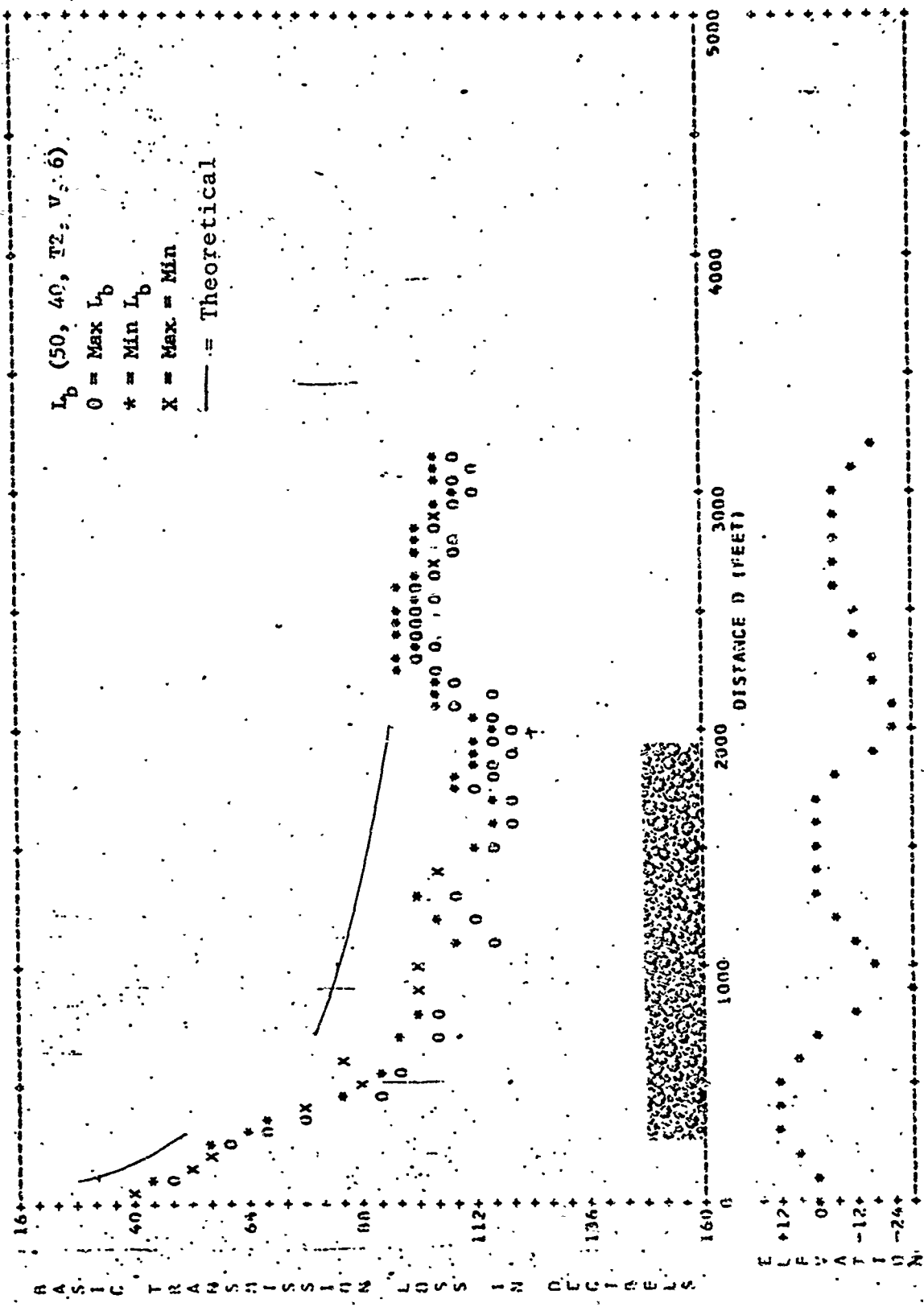


Figure 5.2.36 Basic Transmission Loss and Terrain Elevation vs Distance for Configuration B-0

MIXED PATH BASIC TRANSMISSION LOSS
WALKING DATA CONFIGURATION R-0, TRANSMITTER Y-2
FREQ. = 50MHz, Ht. = 40FT., POL. = V

DIST(FT)	MINLR(DBI)	MAXLR(DBI)	WLS(FT)	MINLR(DBI)	MAXLR(DBI)
50.0	39.9	40.9	100.0	45.1	46.1
150.0	50.8	51.8	200.0	54.1	55.1
250.0	56.2	58.2	300.0	64.3	66.3
350.0	69.3	74.3	400.0	76.4	77.4
450.0	85.4	92.4	500.0	86.4	88.4
550.0	92.4	94.4	600.0	84.4	85.4
650.0	99.4	99.4	700.0	96.4	102.4
750.0	99.4	99.4	800.0	100.4	104.4
850.0	99.4	99.4	900.0	98.4	98.4
950.0	99.4	99.4	1000.0	98.4	100.4
1050.0	99.4	99.4	1100.0	106.4	114.4
1150.0	99.4	99.4	1200.0	102.4	110.4
1250.0	99.4	99.4	1300.0	107.4	106.4
1350.0	99.4	99.4	1400.0	103.4	105.4
1450.0	99.4	99.4	1500.0	110.4	116.4
1550.0	99.4	99.4	1600.0	114.4	118.4
1650.0	99.4	99.4	1700.0	116.4	120.4
1750.0	106.4	112.4	1800.0	108.4	117.4
1850.0	110.4	116.4	1900.0	110.4	118.4
1950.0	112.4	116.4	2000.0	115.4	118.4
2050.0	112.4	116.4	2100.0	105.4	108.4
2150.0	105.4	115.4	2200.0	102.4	106.4
2250.0	95.4	102.4	2300.0	95.4	100.4
2350.0	100.4	102.4	2400.0	96.4	98.4
2450.0	96.4	98.4	2500.0	96.4	99.4
2550.0	99.4	102.4	2600.0	97.4	101.4
2650.0	98.4	102.4	2700.0	102.4	104.4
2750.0	100.4	108.4	2800.0	101.4	109.4
2850.0	99.4	105.4	2900.0	102.4	103.4
2950.0	104.4	106.4	3000.0	106.4	112.4
3050.0	104.4	107.4	3100.0	105.4	113.4
3150.0	105.4	108.4	3200.0	****	****

Figure 5.2.36 Continued

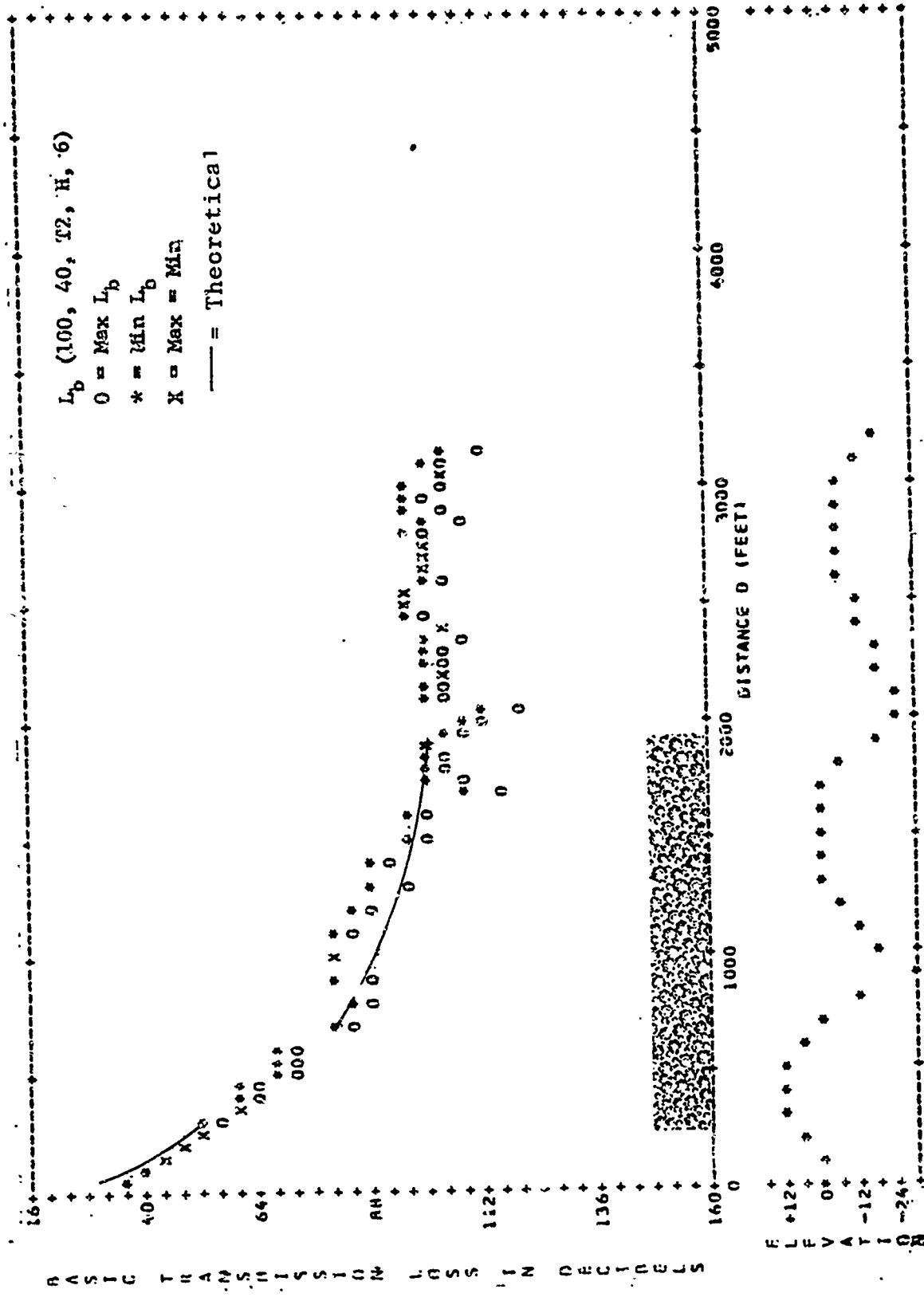


Figure 5.2.37 Basic Transmission Loss and Terrain Elevation vs Distance for Configuration B-0

MIXED PATH BASIC TRANSMISSION LOSS
WALKING DATA CONFIGURATION H-0, TRANSMITTER T-2

FREQ.=100MHZ., HT.= 40FT., POL.=H

DIST(FT)	MINLR(DB)	MAXLR(DB)	DIST(FT)	HINLR(DB)	MAXLR(DB)
50.0	35.2	****	100.0	39.2	****
150.0	42.2	63.2	200.0	47.2	49.2
250.0	50.2	52.2	300.0	53.2	55.2
350.0	58.2	60.2	400.0	58.2	62.2
450.0	60.2	62.2	500.0	67.2	72.2
550.0	64.2	71.2	600.0	69.2	70.2
650.0	****	****	700.0	79.2	85.2
750.0	****	****	800.0	83.2	89.2
850.0	****	****	900.0	79.2	89.2
950.0	****	****	1000.0	79.2	81.2
1050.0	****	****	1100.0	81.2	83.2
1150.0	****	****	1200.0	85.2	88.2
1250.0	****	****	1300.0	89.2	97.2
1350.0	****	****	1400.0	89.2	91.2
1450.0	****	****	1500.0	95.2	101.2
1550.0	****	****	1600.0	95.2	99.2
1650.0	****	****	1700.0	107.2	116.2
1750.0	100.2	107.2	1800.0	99.2	105.2
1850.0	99.2	105.2	1900.0	90.2	100.2
1950.0	103.2	107.2	2000.0	106.2	110.2
2050.0	112.2	120.2	2100.0	100.2	103.2
2150.0	101.2	103.2	2200.0	103.2	105.2
2250.0	101.2	103.2	2300.0	101.2	105.2
2350.0	101.2	107.2	2400.0	104.2	105.2
2450.0	97.2	98.2	2500.0	95.2	97.2
2550.0	96.2	97.2	2600.0	98.2	102.2
2650.0	98.2	101.2	2700.0	99.2	100.2
2750.0	98.2	100.2	2800.0	97.2	100.2
2850.0	99.2	107.2	2900.0	97.2	105.2
2950.0	97.2	101.2	3000.0	97.2	104.2
3050.0	102.2	104.2	3100.0	101.2	105.2
3150.0	105.2	110.2	3200.0	****	****

Figure 5.2.37 Continued

MIXED PATH BASIC TRANSMISSION LOSS
WALKING DATA CONFIGURATION R-0, TRANS-1 (TIER T-2)

FREQ.=100MHZ, HT.= 40FT., PDL.=V

DIST(FT)	MINLR(DB)	MAXLR(DB)	DIST(FT)	MINLR(DB)	MAXLR(DB)
50.0	36.6	40.6	100.0	44.8	49.8
150.0	47.5	51.5	200.0	51.8	55.8
250.0	53.9	62.9	300.0	61.0	65.0
350.0	61.1	67.1	400.0	73.1	90.1
450.0	78.1	95.1	500.0	85.1	97.1
550.0	83.1	91.1	600.0	90.1	96.1
650.0	****	****	700.0	99.1	105.1
750.0	****	****	800.0	109.1	114.1
850.0	****	****	900.0	104.2	116.2
950.0	****	****	1000.0	102.2	115.2
1050.0	****	****	1100.0	101.2	115.2
1150.0	****	****	1200.0	101.2	113.2
1250.0	****	****	1300.0	101.2	120.2
1350.0	****	****	1400.0	110.2	123.2
1450.0	****	****	1500.0	110.2	136.2
1550.0	****	****	1600.0	110.2	121.2
1650.0	****	****	1700.0	111.2	127.2
1750.0	108.2	125.2	1800.0	115.2	123.2
1850.0	116.2	129.2	1900.0	116.2	128.2
1950.0	117.2	127.2	2000.0	112.2	123.2
2050.0	116.2	137.2	2100.0	115.2	119.2
2150.0	107.2	125.2	2200.0	109.2	121.2
2250.0	111.2	123.2	2300.0	109.2	116.2
2350.0	106.2	109.2	2400.0	106.2	116.2
2450.0	103.2	110.2	2500.0	101.2	111.2
2550.0	103.2	115.2	2600.0	113.2	125.2
2650.0	105.2	112.2	2700.0	104.2	110.2
2750.0	107.2	125.2	2800.0	105.2	117.2
2850.0	105.2	125.2	2900.0	112.2	121.2
2950.0	109.2	120.2	3000.0	306.2	113.2
3050.0	110.2	116.2	3100.0	115.2	121.2
3150.0	111.2	131.2	3200.0	****	****

Figure 5.2.38 Continued

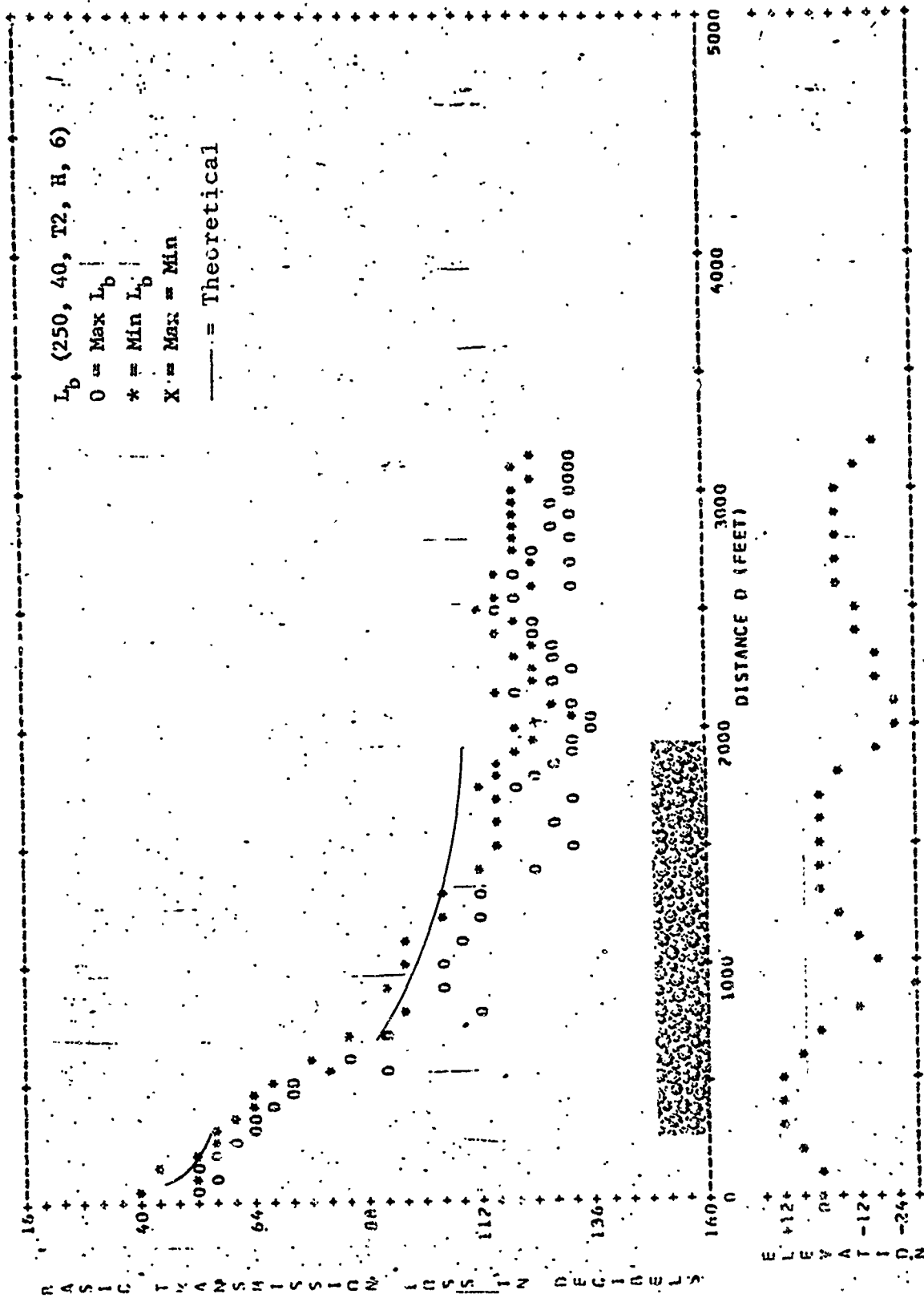


Figure 5.2.39 Basic Transmission Loss and Terrain Elevation Vs Distance for Configuration B-0

MIXED PATH BASIC TRANSMISSION LOSS
WALKING DATA CONFIGURATION 0-0, TRANSMITTER T-2

FREQ.=250MHZ., HT.= 40FT., POL.=H

DIST(FT)	MINLR(DBI)	MAXLR(DBI)	DIST(FT)	MINLR(DBI)	MAXLR(DBI)
50.0	42.0	52.0	100.0	51.0	55.0
150.0	46.0	52.0	200.0	52.0	56.0
250.0	56.0	61.0	300.0	53.0	65.0
350.0	60.0	63.0	400.0	63.0	69.0
450.0	66.0	72.0	500.0	68.0	72.0
550.0	79.0	92.0	600.0	77.0	83.0
650.0	*****	*****	700.0	84.0	94.0
750.0	*****	*****	800.0	95.0	112.0
850.0	*****	*****	900.0	93.0	103.0
950.0	*****	*****	1000.0	99.0	104.0
1050.0	*****	*****	1100.0	98.0	109.0
1150.0	*****	*****	1200.0	104.0	112.0
1250.0	*****	*****	1300.0	105.0	114.0
1350.0	*****	*****	1400.0	111.0	126.0
1450.0	*****	*****	1500.0	117.0	132.0
1550.0	*****	*****	1600.0	117.0	127.0
1650.0	*****	*****	1700.0	118.0	137.0
1750.0	114.0	120.0	1800.0	118.0	124.0
1850.0	117.0	128.0	1900.0	122.0	132.0
1950.0	124.0	133.0	2000.0	120.0	136.0
2050.0	132.0	136.0	2100.0	128.0	134.0
2150.0	116.0	122.0	2200.0	124.0	128.0
2250.0	124.0	132.0	2300.0	121.0	128.0
2350.0	124.0	130.0	2400.0	118.0	123.0
2450.0	120.0	124.0	2500.0	117.0	118.0
2550.0	115.0	127.0	2600.0	124.0	132.0
2650.0	116.0	122.0	2700.0	123.0	132.0
2750.0	120.0	126.0	2800.0	121.0	132.0
2850.0	120.0	130.0	2900.0	121.0	131.0
2950.0	120.0	128.0	3000.0	120.0	132.0
3050.0	126.0	134.0	3100.0	120.0	132.0
3150.0	124.0	132.0	3200.0	*****	*****

Figure 5.2.39 Continued

MIXED PATH BASIC TRANSMISSION LOSS
WALKING DATA CONFIGURATION B-0, TRANSMITTER T-2
FREQ.=250MHZ., HT.= 40F1., POL.=V

DIST(FT)	MINLR(DB)	MAXLR(DB)	DIST(FT)	MINLR(DB)	MAXLR(DB)
50.0	50.6	56.6	100.0	52.9	55.9
150.0	55.6	61.6	200.0	58.9	64.9
250.0	63.0	71.0	300.0	64.1	74.1
350.0	77.1	93.1	400.0	75.1	89.1
450.0	85.2	95.2	500.0	86.2	95.2
550.0	95.2	105.2	600.0	112.2	116.2
650.0	****	****	700.0	111.2	123.2
750.0	****	****	800.0	113.2	133.2
850.0	****	****	900.0	120.2	133.2
950.0	****	****	1000.0	117.2	127.2
1050.0	****	****	1100.0	121.2	133.2
1150.0	****	****	1200.0	120.2	133.2
1250.0	****	****	1300.0	121.2	134.2
1350.0	****	****	1400.0	125.2	131.2
1450.0	****	****	1500.0	122.2	131.2
1550.0	****	****	1600.0	130.2	134.2
1650.0	****	****	1700.0	132.2	143.2
1750.0	115.2	145.2	1800.0	131.2	145.2
1850.0	141.2	153.1	1900.0	134.2	145.2
1950.0	142.2	149.2	2000.0	131.2	145.2
2050.0	133.2	147.2	2100.0	135.2	148.2
2150.0	132.2	145.2	2200.0	131.2	135.2
2250.0	126.2	132.2	2300.0	124.2	135.2
2350.0	124.2	135.2	2400.0	125.2	131.2
2450.0	127.2	142.2	2500.0	124.2	145.2
2550.0	126.2	147.2	2600.0	127.2	144.2
2650.0	126.2	147.2	2700.0	127.2	142.2
2750.0	129.2	143.2	2800.0	129.2	147.2
2850.0	127.2	135.2	2900.0	124.2	134.2
2950.0	124.2	132.2	3000.0	125.2	135.2
3050.0	124.2	136.2	3100.0	127.2	143.2
3150.0	110.2	135.2	3200.0	****	****

Figure 5.2.40 Continued

5.2.48 show the basic transmission loss as a function of distance, with the terrain profile shown, for the transmitter at T1 in the B8 configuration. The experimental parameters involved in the basic transmission loss L_b are identified by the functional form of

$$L_b (f, H_T, T, P, H_R)$$

where f is frequency in megahertz, H_T and H_R are transmitter and receiver antenna heights, respectively, in feet above local ground, T is the transmitter location, and P the polarization, either horizontal, H , or vertical, V . The tabulated L_b are shown on the height-gain curves and on an accompanying page for the walking data. Some observations of gross behavior may be made from a brief examination of the experimental results of these figures:

(1) The walking data show that there is considerable spatial variability in the basic transmission loss (i.e., difference in maximum and minimum L_b) and the maximum L_b tends to vary greater than the minimum L_b .

(2) The walking data show that the transmission loss tends to correlate with the dominant terrain features, being relatively greater in the depressed areas and smaller as the ground rises.

(3) The walking data show that when the receiver moves from vegetation to clearing (with vegetation between the transmitter and the receiver) the loss generally tends to decrease (signal increases); however, when the loss does increase for a short distance, it is at a relatively smaller rate.

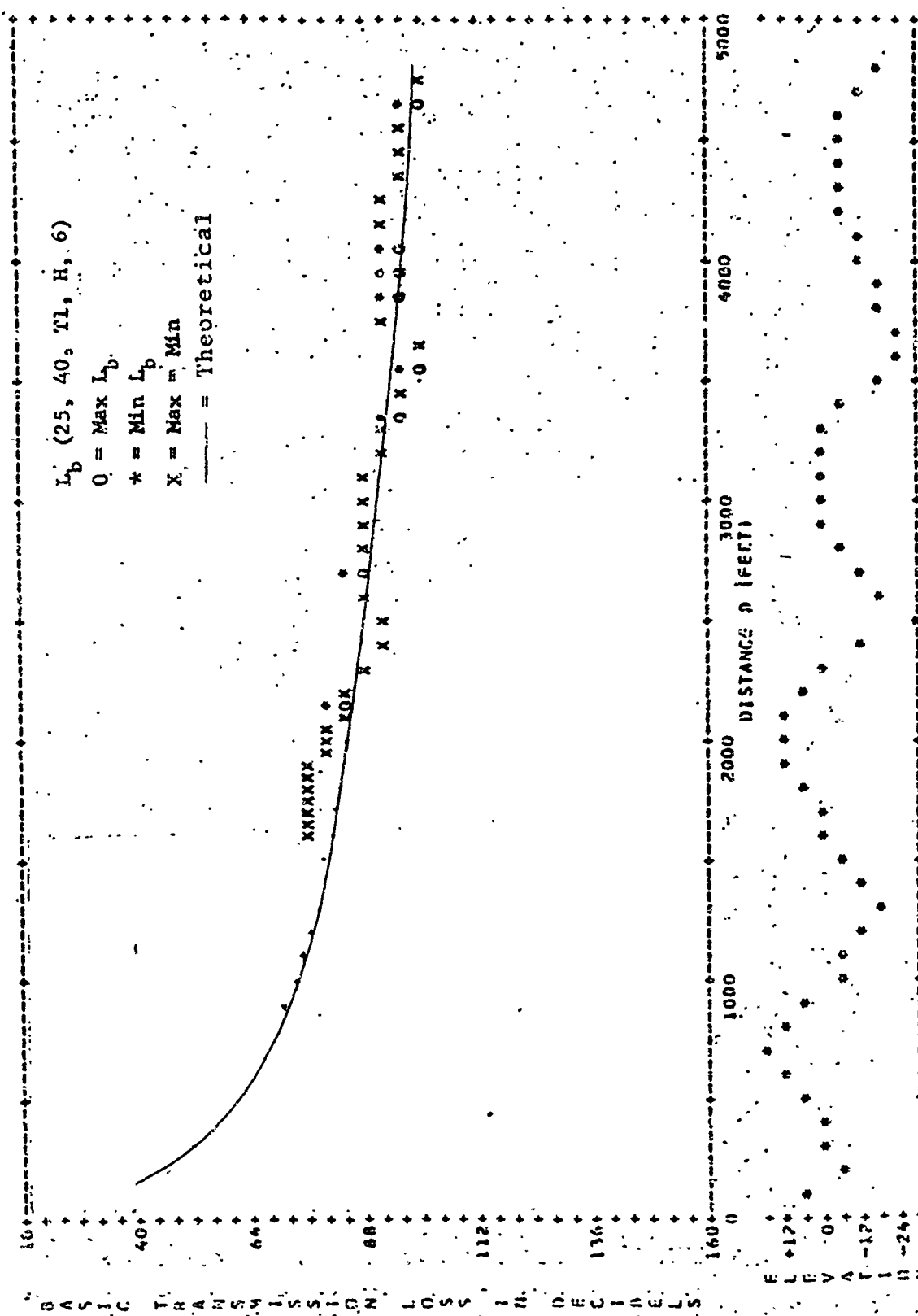


Figure 5.2.41 Basic Transmission Loss and Terrain Elevation vs Distance for Configuration B-8

MIXED PATH BASIC TRANSMISSION LOSS
WALKING DATA CONFIGURATION B-H, TRANSMITTER T-1

FREQ. = 25MHZ., HT. = 40FT., POL. = H

RIS (FT)	MIN (DB)	MAX (DB)
1630.0	76.0	76.0
1650.0	75.0	76.0
1700.0	75.0	76.0
1750.0	75.0	76.0
1800.0	76.0	76.0
1850.0	76.0	77.0
1900.0	77.0	78.0
1950.0	79.0	80.0
2000.0	80.0	81.0
2050.0	81.0	82.0
2100.0	83.0	83.0
2150.0	82.0	85.0
2200.0	84.0	84.0
2300.0	88.0	89.0
2400.0	91.0	91.0
2500.0	91.0	92.0
2600.0	87.0	88.0
2700.0	86.0	88.0
2800.0	87.0	88.0
2900.0	87.0	89.0
3050.0	87.0	89.0
3100.0	90.0	90.0
3200.0	92.0	93.0
3300.0	92.0	94.0
3350.0	94.0	95.0
3450.0	97.0	97.0
3550.0	98.0	99.0
3650.0	100.0	101.0
3750.0	94.0	94.0
3850.0	94.0	95.0
3950.0	94.0	95.0
4050.0	94.0	94.0
4150.0	94.0	94.0
4250.0	95.0	96.0
4350.0	95.0	97.0
4450.0	96.0	97.0
4550.0	96.0	99.0
4650.0	97.0	101.0
4750.0	94.0	

Figure 5 2.41 Continued

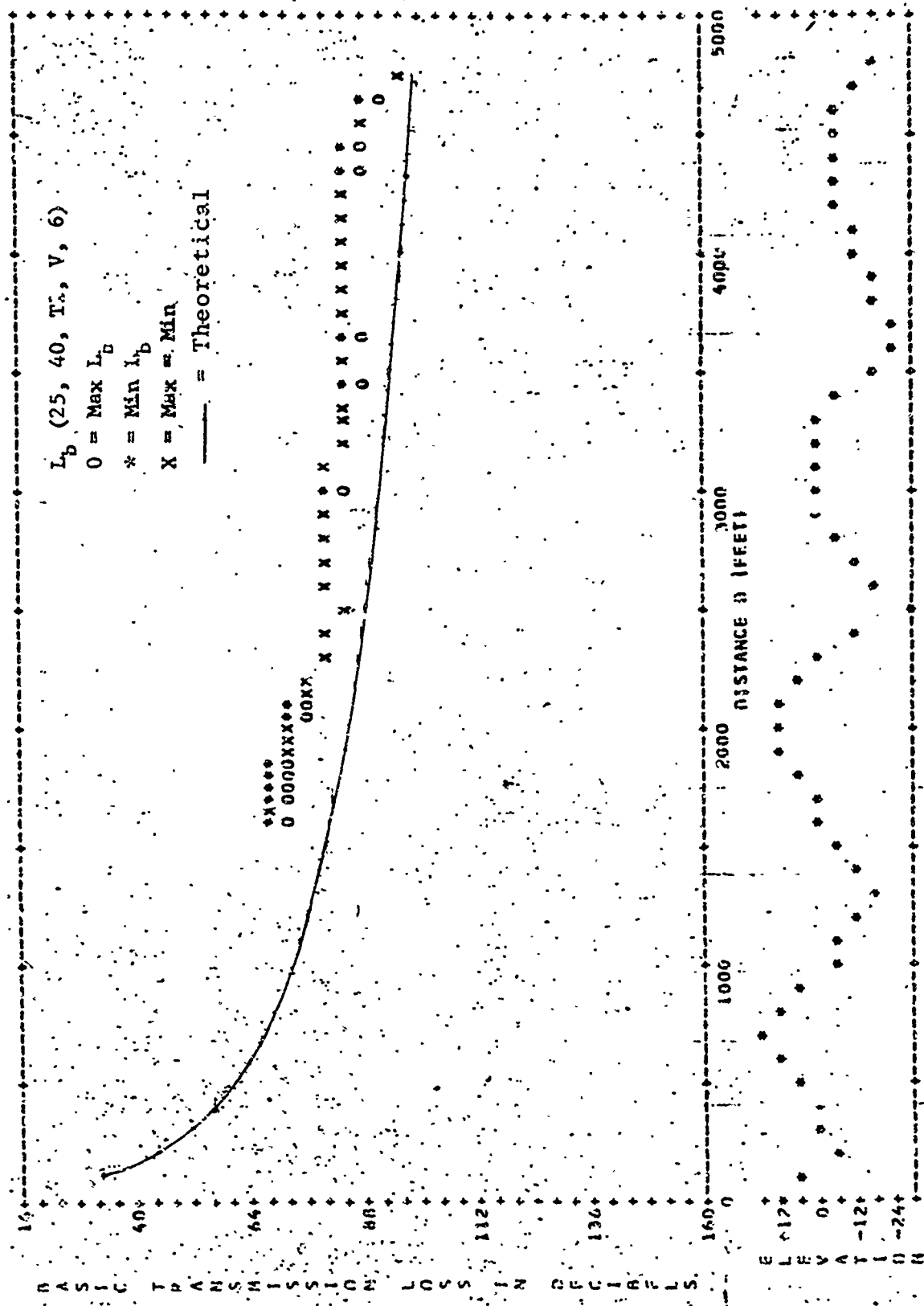


Figure 5.2.42 Basic Transmission Loss and Terrain Elevation vs Distance for Configuration 3-8

MIXED PATH BASIC TRANSMISSION LOSS
WALKING DATA CONFIGURATION 0-0, TRANSMITTER T-1

FRF3 = 25MHz, HT = 50FT, POL = V

DIST(FT)	MINL(Db)	MAXL(Db)
1600.0	69.0	71.0
1650.0	69.0	70.0
1700.0	69.0	71.0
1750.0	70.0	71.0
1800.0	69.0	71.0
1850.0	70.0	71.0
1900.0	71.0	71.0
1950.0	71.0	73.0
2000.0	72.0	74.0
2050.0	71.0	75.0
2100.0	74.0	75.0
2150.0	75.0	76.0
2200.0	75.0	77.0
2300.0	81.0	82.0
2400.0	79.0	81.0
2500.0	81.0	83.0
2600.0	79.0	81.0
2700.0	79.0	80.0
2800.0	90.0	91.0
2900.0	80.0	82.0
3000.0	81.0	93.0
3100.0	80.0	82.0
3200.0	86.0	86.0
3300.0	85.0	86.0
3350.0	85.0	85.0
3450.0	85.0	87.0
3550.0	86.0	86.0
3650.0	86.0	86.0
3750.0	85.0	86.0
3850.0	84.0	85.0
3950.0	83.0	85.0
4050.0	85.0	86.0
4150.0	85.0	86.0
4250.0	86.0	86.0
4350.0	86.0	88.0
4450.0	86.0	88.0
4550.0	84.0	89.0
4650.0	90.0	92.0
4750.0	95.0	96.0

Figure 5.2.42 Continued

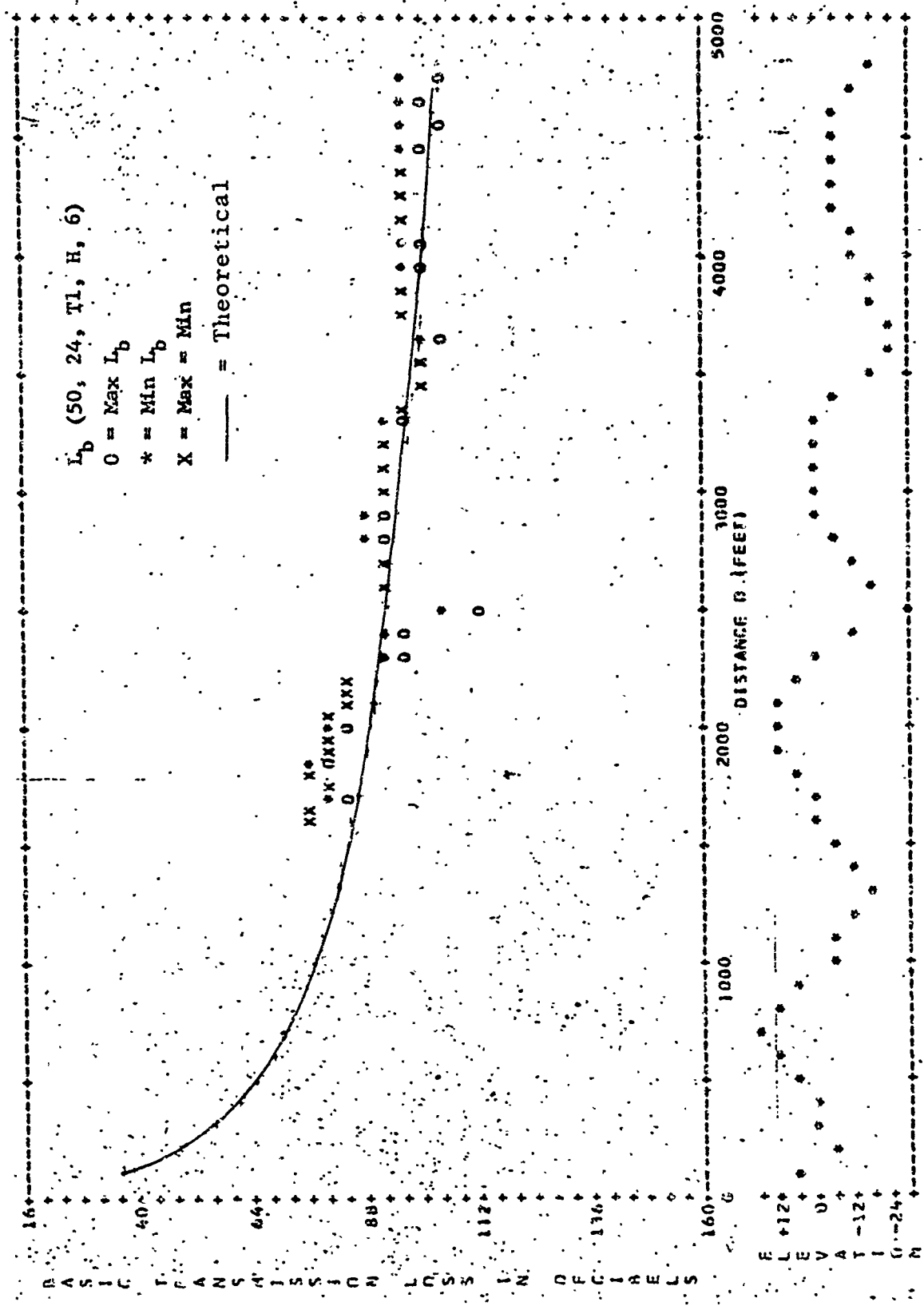


Figure 5.2.43 Basic Transmission Loss and Terrain Elevation vs Distance for Configuration B-8

FIXED PATH BASIC TRANSMISSION LOSS
WALKING DATA CONFIGURATION R-8, TRANSMITTER T-1

FREQ. = 50MHZ., HT. = 24FT., POL. = H

DIST(FT)	MINLR(DR)	MAXLR(DR)
1600.0	75.7	76.7
1650.0	75.7	77.7
1700.0	80.7	82.7
1750.0	78.7	79.7
1800.0	77.7	77.7
1850.0	76.7	81.7
1900.0	78.7	81.7
1950.0	79.7	81.7
2000.0	80.7	82.7
2050.0	81.7	81.7
2100.0	82.7	84.7
2150.0	82.7	84.7
2200.0	83.7	85.7
2300.0	91.7	94.7
2400.0	91.7	95.7
2500.0	104.7	113.7
2600.0	90.7	93.7
2700.0	91.7	93.7
2800.0	89.7	93.7
2900.0	81.7	92.7
3000.0	90.7	97.7
3100.0	91.7	91.7
3200.0	91.7	93.7
3300.0	91.7	95.7
3350.0	95.7	97.7
3450.0	99.7	100.7
3550.0	99.7	101.7
3650.0	100.7	102.7
3750.0	95.7	96.7
3850.0	94.7	95.7
3950.0	96.7	98.7
4050.0	95.7	98.7
4150.0	95.7	95.7
4250.0	95.7	95.7
4350.0	95.7	97.7
4450.0	95.7	99.7
4550.0	95.7	104.7
4650.0	95.7	99.7
4750.0	96.7	102.7

Figure 5.2.43 Continued

MIXED PATH BASIC TRANSMISSION LOSS
WALKING DATA CONFIGURATION 5-8, TRANSMITTER T-1

FREQ. = 50MHZ., HT. = 24FT., POL. = V

DIST(FT)	MINLR(DD)	MAXLR(DD)
1600.0	74.7	77.7
1650.0	76.7	81.7
1700.0	79.7	86.7
1750.0	80.7	84.7
1800.0	76.7	80.7
1850.0	78.7	80.7
1900.0	77.7	79.7
1950.0	73.7	81.7
2000.0	76.7	82.7
2050.0	79.7	80.7
2100.0	79.7	85.7
2150.0	82.7	86.7
2200.0	83.7	90.7
2300.0	95.7	99.7
2400.0	99.7	109.7
2500.0	106.7	113.7
2600.0	99.7	112.7
2700.0	101.7	109.7
2800.0	95.7	105.7
2900.0	95.7	106.7
3000.0	95.7	100.7
3100.0	97.7	103.7
3200.0	99.7	111.7
3300.0	97.7	103.7
3350.0	102.7	112.7
3450.0	104.7	112.7
3550.0	99.7	102.7
3650.0	103.7	107.7
3750.0	77.7	99.7
3850.0	91.7	95.7
3950.0	90.7	94.7
4050.0	91.7	97.7
4150.0	90.7	93.7
4250.0	90.7	96.7
4350.0	93.7	97.7
4450.0	91.7	103.7
4550.0	91.7	97.7
4650.0	94.7	97.7
4750.0	91.7	96.7

Figure 5.2.44 Continued

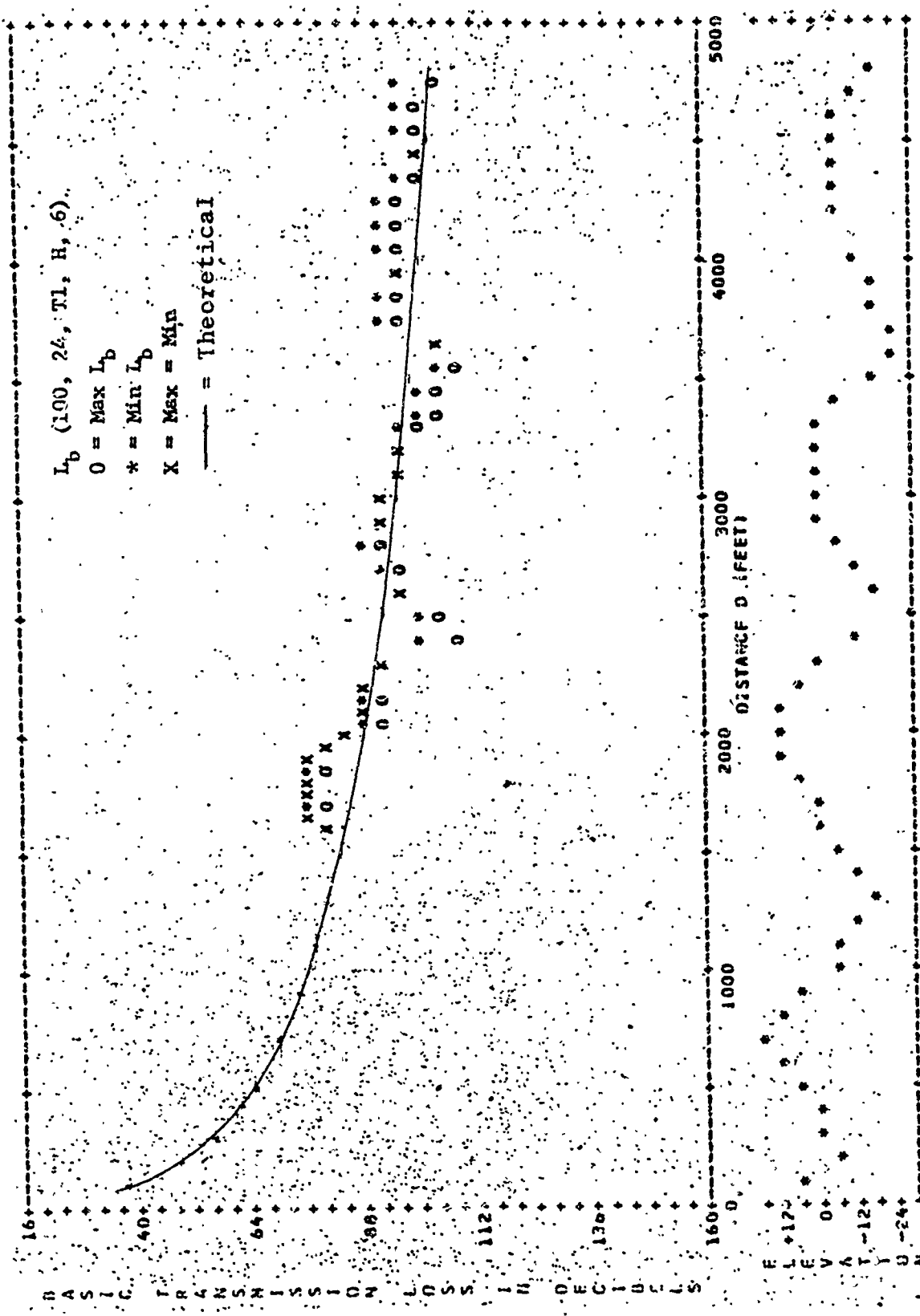


Figure 5.2.45 Basic Transmission Loss and Terrain Elevation vs Distance for Configuration B-8

MIXED PATH BASIC TRANSMISSION LOSS
WALKING DATA CONFIGURATION H-8, TRANSMITTER T-1

FREQ.=100MHZ., HT.= 24FT., POL.=H

DIST(FT)	MINLO(DB)	MAXL(BDB)
1600.0	79.6	79.6
1650.0	75.6	76.6
1700.0	77.6	73.6
1750.0	76.6	77.6
1800.0	75.6	77.6
1850.0	75.6	80.6
1900.0	76.6	77.6
1950.0	90.6	80.6
2000.0	87.6	85.6
2050.0	87.6	90.6
2100.0	88.6	88.6
2150.0	88.6	90.6
2200.0	88.6	88.6
2250.0	92.6	92.6
2300.0	106.6	106.6
2350.0	100.6	105.6
2400.0	94.6	96.6
2450.0	93.6	94.6
2500.0	88.6	90.6
2550.0	90.6	92.6
2600.0	90.6	92.6
2650.0	95.6	96.6
2700.0	94.6	96.6
2750.0	96.6	98.6
2800.0	100.6	102.6
2850.0	100.6	103.6
2900.0	104.6	108.6
2950.0	102.6	104.6
3000.0	93.6	95.6
3050.0	97.6	94.6
3100.0	94.6	96.6
3150.0	96.6	98.6
3200.0	100.6	102.6
3250.0	100.6	103.6
3300.0	104.6	108.6
3350.0	102.6	104.6
3400.0	93.6	95.6
3450.0	97.6	94.6
3500.0	94.6	96.6
3550.0	93.6	94.6
3600.0	93.6	94.6
3650.0	93.6	94.6
3700.0	94.6	96.6
3750.0	94.6	96.6
3800.0	94.6	96.6
3850.0	94.6	96.6
3900.0	94.6	96.6
3950.0	94.6	96.6
4000.0	94.6	96.6
4050.0	94.6	96.6
4100.0	94.6	96.6
4150.0	94.6	96.6
4200.0	94.6	96.6
4250.0	94.6	96.6
4300.0	94.6	96.6
4350.0	94.6	96.6
4400.0	94.6	96.6
4450.0	94.6	96.6
4500.0	94.6	96.6
4550.0	94.6	96.6
4600.0	94.6	96.6
4650.0	94.6	96.6
4700.0	94.6	96.6
4750.0	94.6	96.6

Figure 5.2.45 Continued

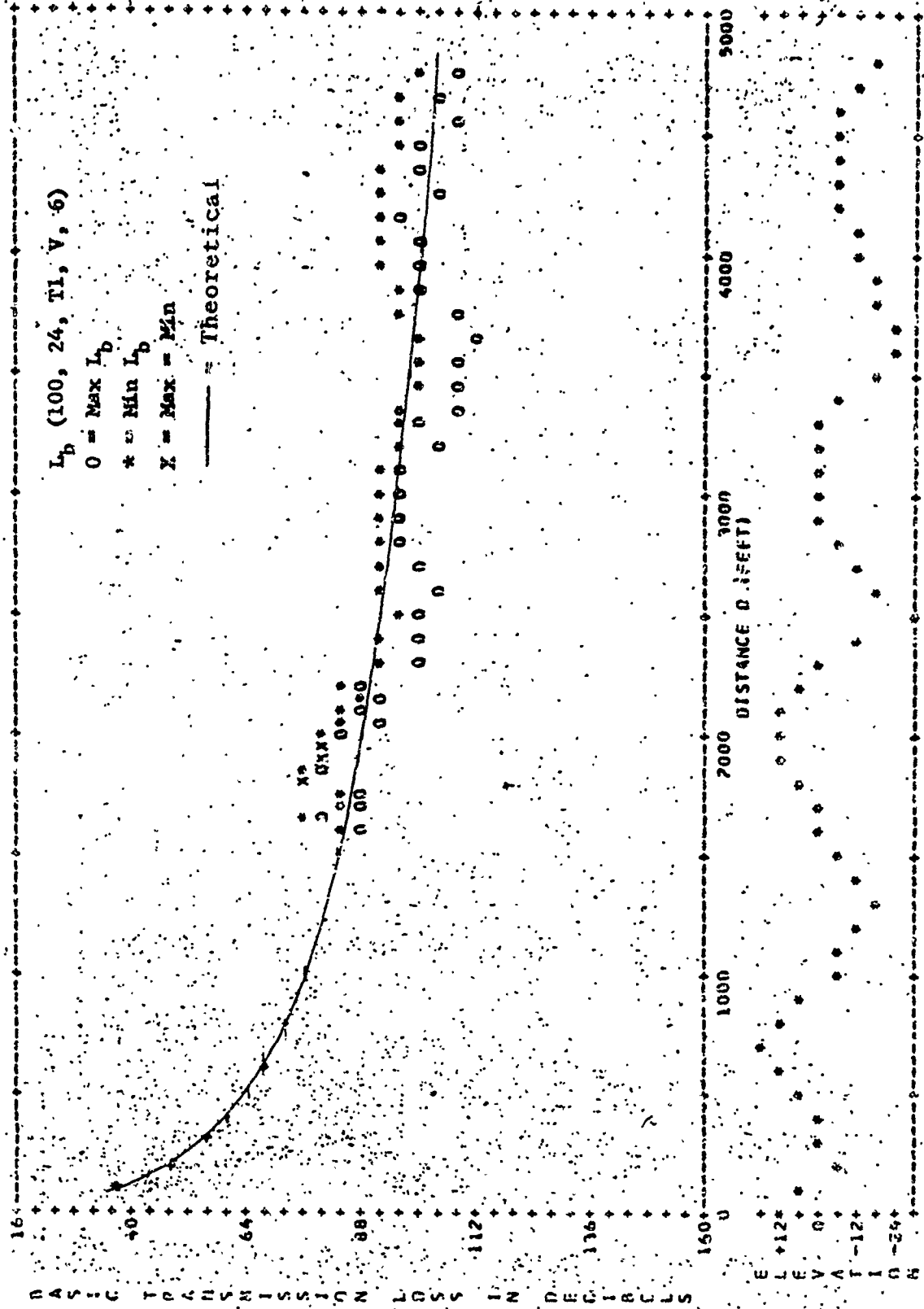


Figure 5.2.46 Basic Transmission Loss and Terrain Elevation vs Distance for Configuration B-8

MIXED PATH BASIC TRANSMISSION LOSS
WALKING DATA CONFIGURATION II-E, TRANSMITTER T-1

FREQ.=100MHZ, HT.= 24FT., PUL.=V

DIST(FT)	MIN(L) (DB)	MAX(L) (DB)
1600.0	83.6	89.6
1650.0	76.6	80.6
1700.0	84.6	89.6
1750.0	82.6	89.6
1800.0	75.6	77.6
1850.0	76.6	40.6
1900.0	80.6	81.6
1950.0	78.6	81.6
2000.0	81.6	84.6
2050.0	85.6	90.6
2100.0	82.6	87.6
2150.0	87.6	92.6
2200.0	85.6	88.6
2250.0	90.6	99.6
2300.0	93.6	99.6
2350.0	94.6	100.6
2400.0	91.6	104.6
2450.0	91.6	101.6
2500.0	90.6	95.6
2550.0	91.6	96.6
2600.0	92.6	97.6
2650.0	91.6	97.6
2700.0	95.6	105.6
2750.0	97.6	100.6
2800.0	96.6	109.6
2850.0	94.6	106.6
2900.0	101.6	107.6
2950.0	101.6	110.6
3000.0	96.6	109.6
3050.0	94.6	98.6
3100.0	93.6	99.6
3150.0	91.6	99.6
3200.0	91.6	94.6
3250.0	91.6	103.6
3300.0	95.6	101.6
3350.0	95.6	106.6
3400.0	94.6	94.6
3450.0	101.6	94.6
3500.0	101.6	94.6
3550.0	96.6	94.6
3600.0	94.6	94.6
3650.0	93.6	94.6
3700.0	91.6	94.6
3750.0	91.6	94.6
3800.0	91.6	94.6
3850.0	95.6	94.6
3900.0	95.6	106.6
3950.0	94.6	105.6
4000.0	101.6	108.6

Figure 5.2.46 Continued

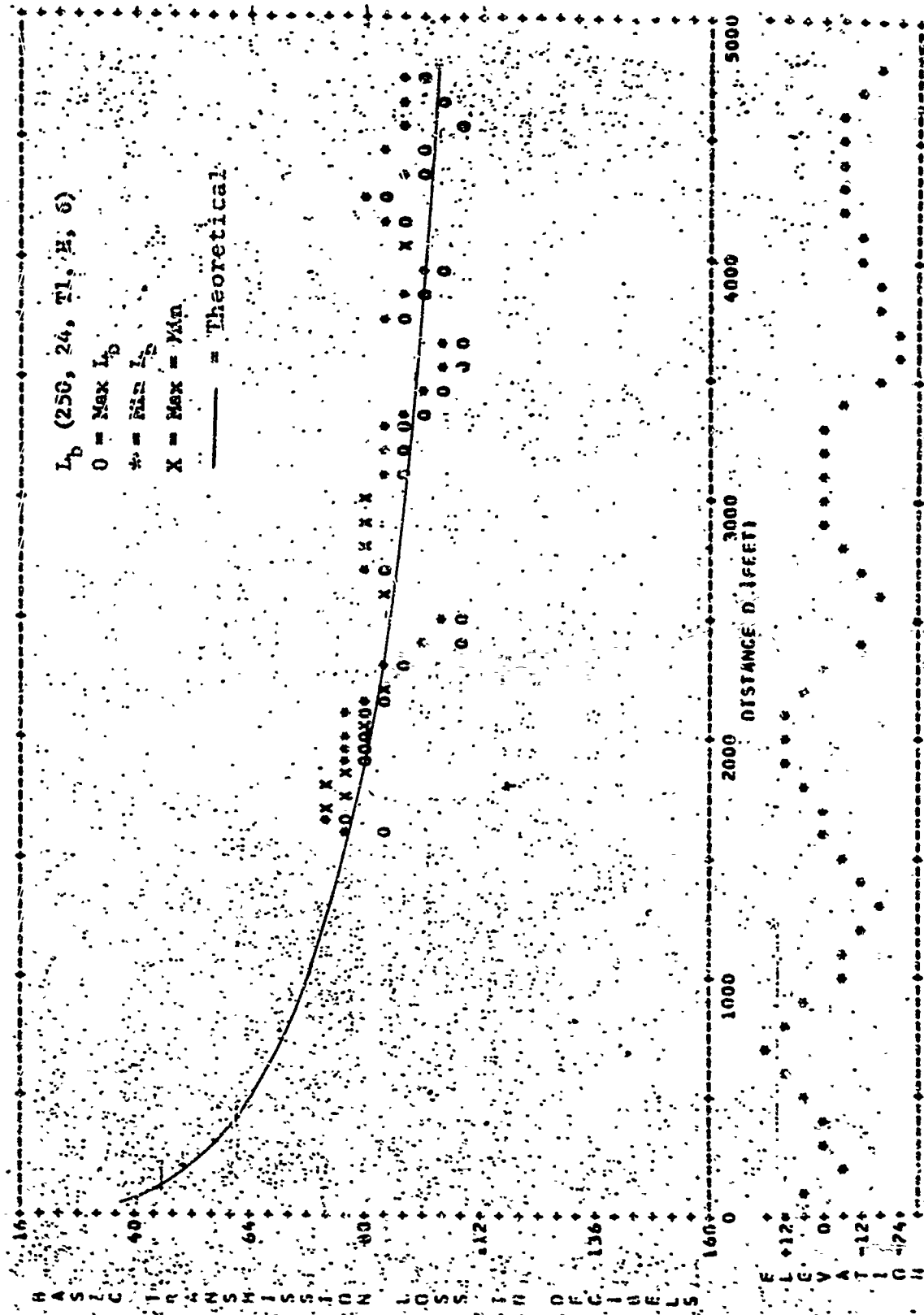


Figure 5.2.47 Basic Transmission Loss and Terrain Elevation vs Distance for Configuration B-8

MIXED PATH BASIC TRANSMISSION LOSS
WALKING DATA CONFIGURATION D-8, TRANSMITTER T-1

FRQ.=250MHZ., HT.= 24FT., POL.=H

DIST(FT)	MIN(LDB)	MAX(LDB)
1600.0	85.7	90.7
1650.0	81.7	84.7
1700.0	79.7	81.7
1750.0	82.7	84.7
1800.0	80.7	81.7
1850.0	82.7	85.7
1900.0	85.7	86.7
1950.0	85.7	86.7
2000.0	85.7	87.7
2050.0	86.7	88.7
2100.0	86.7	86.7
2150.0	88.7	90.7
2200.0	90.7	92.7
2300.0	92.7	96.7
2400.0	100.7	107.7
2500.0	103.7	107.7
2600.0	91.7	93.7
2700.0	89.7	92.7
2800.0	87.7	89.7
2900.0	87.7	88.7
3000.0	87.7	89.7
3100.0	92.7	94.7
3200.0	93.7	95.7
3300.0	92.7	95.7
3350.0	96.7	98.7
3450.0	100.7	104.7
3550.0	103.7	108.7
3650.0	102.7	107.7
3750.0	92.7	95.7
3850.0	95.7	100.7
3950.0	98.7	104.7
4050.0	14.7	97.7
4150.0	91.7	95.7
4250.0	89.7	92.7
4350.0	94.7	99.7
4450.0	93.7	101.7
4550.0	96.7	106.7
4650.0	96.7	103.7
4750.0	97.7	101.7

Figure 5.2.47 Continued

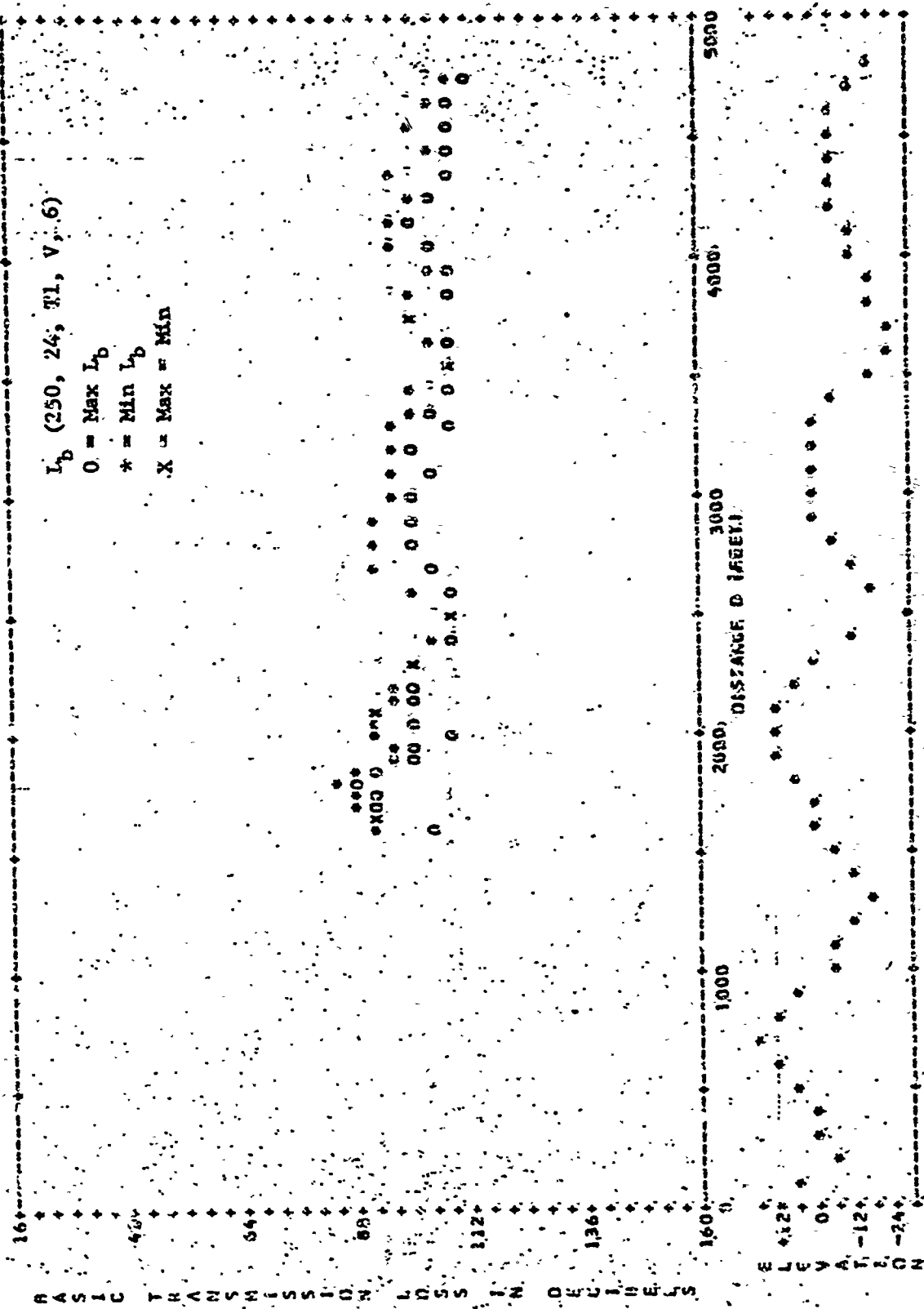


Figure 5.2.48 Basic Transmission Loss and Terrain Elevation vs Distance for Configuration B-8

MIXED PATH BASIC TRANSMISSION LOSS
JACKING DATA CONFIGURATION B-B, TRANSMITTER T-1

FREQ.=250MHZ., HT.= 24FT., POL.=V

DIST(FT.)	MIN(LDB)	MAX(LDB)
1600.0	92.7	104.7
1650.0	90.7	92.7
1700.0	88.7	90.7
1750.0	88.7	90.7
1800.0	85.7	86.7
1850.0	88.7	92.7
1900.0	96.7	99.7
1950.0	94.7	99.7
2000.0	92.7	106.7
2050.0	92.7	98.7
2100.0	90.7	92.7
2150.0	94.7	100.7
2200.0	94.7	101.7
2300.0	98.7	100.7
2400.0	107.7	108.7
2500.0	104.7	138.7
2600.0	98.7	106.7
2700.0	92.7	102.7
2800.0	93.7	100.7
2900.0	92.7	98.7
3000.0	94.7	100.7
3100.0	95.7	102.7
3200.0	96.7	100.7
3300.0	97.7	107.7
3350.0	99.7	104.7
3450.0	101.7	108.7
3550.0	106.7	108.7
3650.0	104.7	108.7
3750.0	98.7	100.7
3850.0	101.7	101.7
3950.0	102.7	106.7
4050.0	97.7	104.7
4150.0	96.7	100.7
4250.0	98.7	102.7
4350.0	96.7	106.7
4450.0	102.7	108.7
4550.0	100.7	108.7
4650.0	107.7	108.7
4750.0	109.7	110.7

Figure 5.2.48 Continued

(4) The walking data show that when the receiver moves from clearing to vegetation there is a short region (called the transition region here) where the loss increases fairly abruptly, after which the loss settles to a lesser rate of increase which is apparently about the same rate of increase as in the clearing.

(5) The height-gain data show that the loss decreases with increasing receiver antenna height.

(6) The walking and height-gain data show that the loss is greater for vertical than horizontal polarization when either antenna is in the foliage with this difference decreasing when both antennas are out of the foliage.

None of these gross observations is unexpected. The signal variability noted in (1) is consistent with the effects of standing waves alluded to in Section 3. In particular, note that the greater variability of the maximum loss (minimum signal) is consistent with the well known fact that the minimum of two interfering waves (causing standing waves) may take on any value less than either of the interfering waves (e.g., possibly total cancellation) while the maximum can at most be 6 db greater than one of the waves (constructive interference).

The gross terrain influence is well known and may be qualitatively identified with the shadow effect in diffraction over an obstacle or, in the case of vegetated terrain, it may be partially due to attenuation over the shorter or longer path that the lateral wave must travel in vegetation at the hills or valleys, respectively, in its downward path from jungle top to the receiver.

The gross behavior at the clearing-vegetation interfaces noted in (3) and (4) is analogous to that observed by Heil [1960].

The observed gross height-gain of (5) is a well known effect with or without foliage.

The effect of anisotropy mentioned in (6) has been observed often in forest environments and is intuitively related to the presence or absence of vertical scatterers (trees), as noted in Section 3.

A theoretical development is given in Section 7, Appendix I, for mixed vegetation-clearing paths over flat earth and specialized to the clearing-foliage path as in B0. The transmission loss in the clearing between transmitter and foliage has been assumed to be due to a space wave over perfect earth with reflections at the clearing-vegetation interface ignored. The transmission loss over the complete path with no foliage (configuration B8) has been computed from the approximate space wave expression of Eq. 7.7, and the results are plotted, along with the experimental data, in Figures 5.2.41 to 5.2.48 for the transmitter antenna height of 24 feet at T1 (except at 25 MHz the height is 40 feet) and the receiver height of 6 feet. The agreement between theory and experiment is good, indicating the simplified space wave is sufficient for this case.

The approximate space wave expression is used to compute the loss in the clearing portion of the mixed clearing-vegetation path discussed next. The resultant approximate solution, for the loss in the foliage for the clearing-vegetation mixed path, where the vegetation segment of the path is assumed

to be a uniform conducting slab, is

$$T_{12} \approx \sqrt{\frac{3}{2}} \frac{\sin(kz_1 H/R) |F(z_2)| x_1^2}{kR(x - x_1)^2 |F(H)|} \quad (5.3.1)$$

$$L_b = -20 \log T_{12}$$

where the symbols and functions have been defined in Section 3 and Appendix I. This has been solved for the transmission loss (in the vegetation segment of the path) as a function of distance for the B0 configuration with the transmitter in the T1 position at a height of 24 feet (except at 25 MHz the height is 40 feet) and at T2 at a height of 40 feet for receiver antenna heights of 6 feet, at frequencies of 25, 50, 100 and 250 MHz and both polarizations.

The resultant theoretical losses in the vegetated segment of the path, for the B-0, T2 configuration, are plotted in Figures 5.2.33 to 5.2.40, along with the experimental results. The theoretical loss in the clearing segment, due to the space wave as discussed above, is also shown. The agreement in the clearing is reasonably good, as discussed above, and the reflections at the interface do not appear to be substantial. The results also show that the theoretical and experimental loss in the foliage segment are in good agreement for horizontal polarization (except at 250 MHz) but are in generally poor agreement for vertical polarization. The difference between theory and experiment for vertical polarization is consistent in that the theoretical loss is less than the experimental loss, as is also the case at 250 MHz for horizontal polarization. The source of the difference has not been determined, but it

could be due to any, or a combination, of several factors. First, the fundamental approach in setting up the problem may be too simplified (e.g., ignoring diffraction over, reflections from, and penetration of the signal directly into the clearing-foilage interface.) Also, the basic fields on the surfaces which are obtained once the problem is set up may be in error (i.e., the simplified space wave comprising part of the total loss and/or the lateral wave fields may be in error.) Further, the manner of solving the resulting equation (i.e., extracting a slowly varying factor to arrive at an analytic approximation to the integral) may lead to some error. It is clear that there is some error due to ignoring the effects in the transition region (i.e., penetration of the wave directly through the clearing-vegetation interface). The direct penetration does not account for the observed error throughout the foliage block, however, since it is known to be rapidly attenuated [Jansky & Bailey, 1956] and it does not seem likely that the effects at the interface will significantly influence the results over the remainder of the path. Thus, the error is probably in the field expressions and/or in the approximate analytical form used for the integral. There is, of course, some error in the lateral wave fields which, as noted in Sections 3 and 4, could be reduced by obtaining frequency dependent electrical constants and effective height for the slab model. This would not account for the total error at vertical polarization, however, and a numerical integration, with as few analytic approximations as possible, appears to be necessary to further refine the basic theoretical approach presented in this report.

The transition region (i.e., the region of sudden increase in loss as the receiver passes from clearing to vegetation) has been alluded to above and intuitively associated with the loss of energy of the wave in the vegetation which penetrates directly through the clearing-vegetation interface. In

order to examine the transition region more carefully, the minimum experimental transmission loss for the B0 configuration is subtracted from the minimum transmission loss for the B2 configuration (foliage removed). The results are plotted in Figures 5.2.49 to 5.2.56 for the transmitter at T1, for frequencies of 25, 50, 100 and 250 MHz, at both polarizations and various transmitter antenna heights. For vertical polarization, the length of the transition region appears to increase somewhat with increasing frequency and, with the exception of that at 25 MHz, the average difference in the loss beyond the transition region, which generally settles to a constant in the vegetation, decreases with increasing frequency. The relatively large loss in the vegetation with the B0 configuration at 25 MHz for vertical polarization at the lower antenna heights has been mentioned previously [Jansky & Bailey, 1965] and appears to be consistent throughout in Areas I and II.

For horizontal polarization, the foliage appears to have little effect at 25 MHz and no transition region is apparent. At 50 and 100 MHz (horizontal polarization) the loss is generally greater in the foliage than when the foliage is removed, by about 5 db beyond the transition region. The transition region appears to be about 1000 to 1500 feet long, but the variability in the data makes this a qualitative determination at best. At 250 MHz, horizontal polarization, the loss in the foliage is much greater (≈ 25 db) than without the foliage and a transition region of about 1000 feet is indicated. Also, the transition region is somewhat larger than the apparent 200 - 300 foot distance of rapidly increasing loss when the transmitter and receiver are in an all-vegetated path [Jansky & Bailey, 1966].

The difference in the loss beyond the transition region, as shown in Figures 5.2.49 to 5.2.56, may be seen to

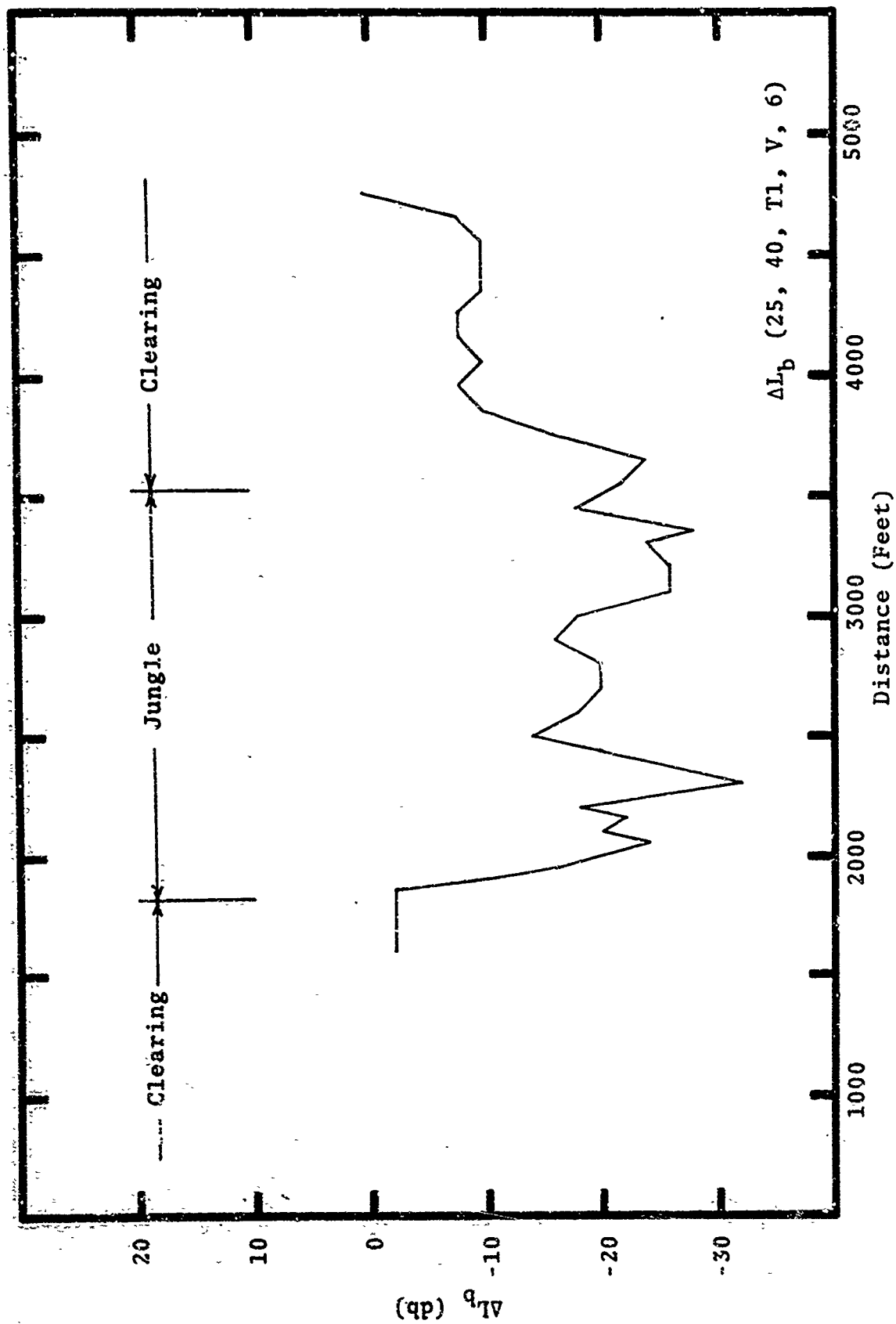


Figure 5.2.49 Basic Transmission Loss Without Vegetation (B_3) Minus Loss With Vegetation (R_0) as a Function of Distance

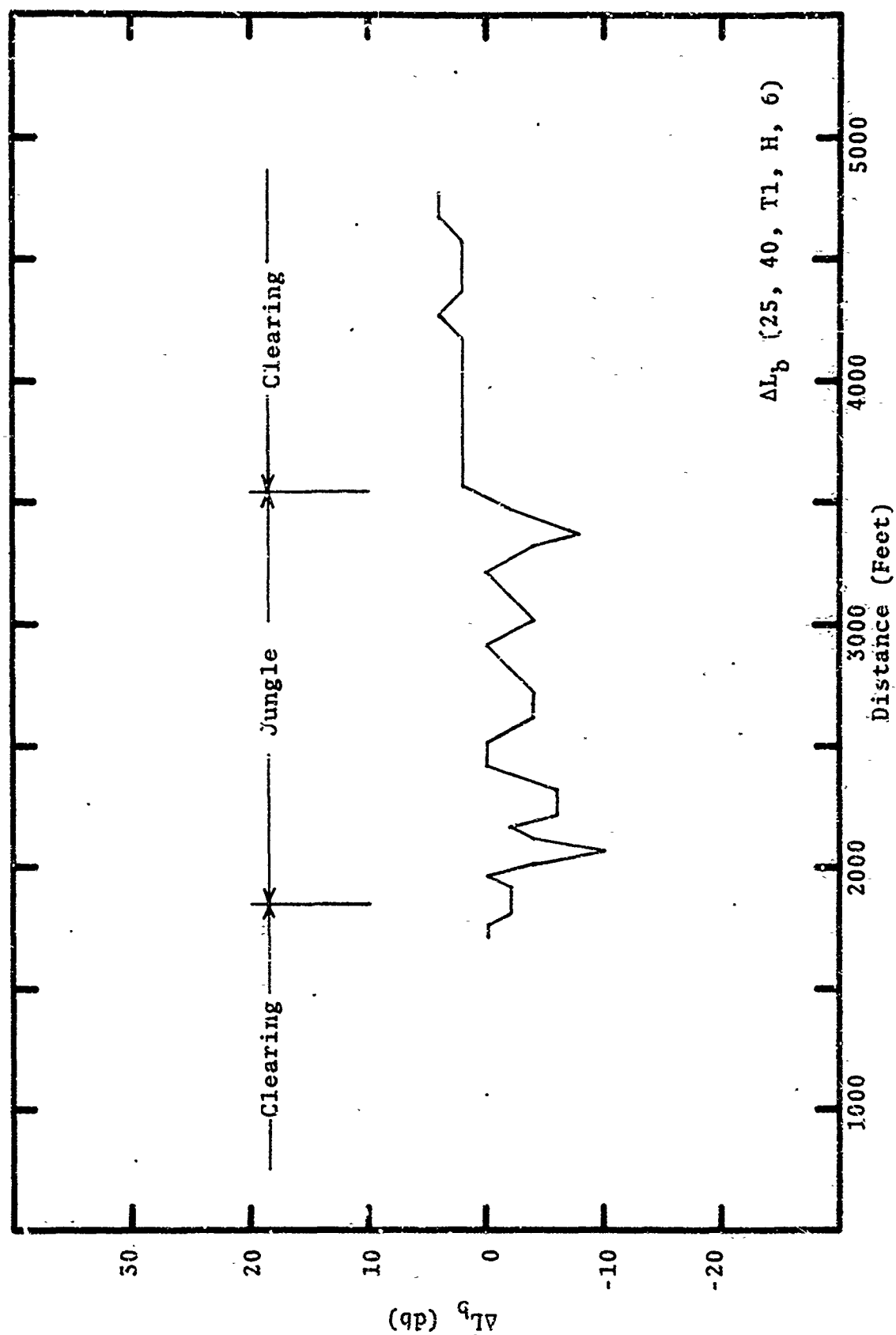


Figure 5.2.50 Basic Transmission Loss Without Vegetation (B8) Minus Loss With Vegetation (B0) as a Function of Distance

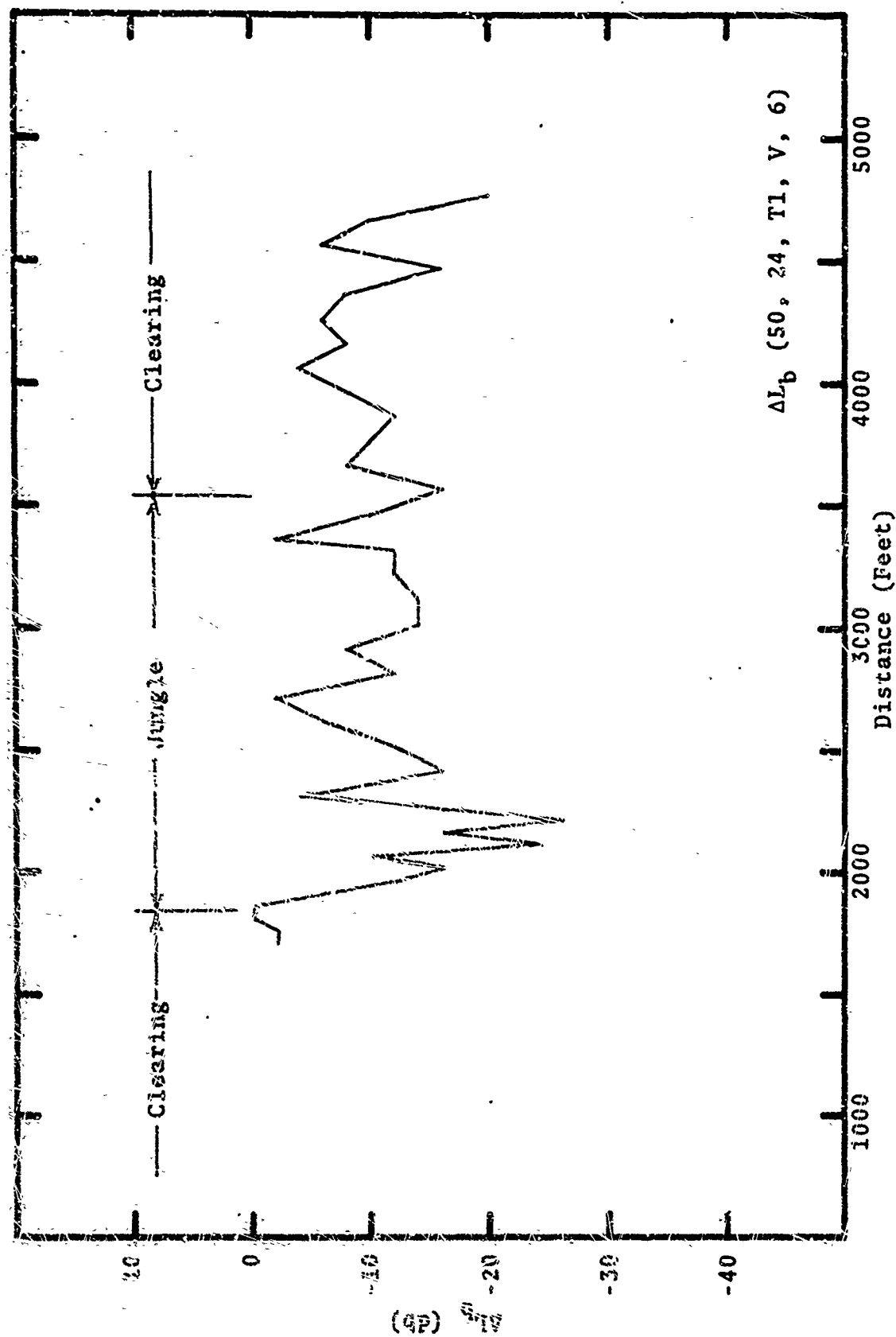


Figure 5.2.51 Basic Transmission Loss Without Vegetation (B8) Minus Loss With Vegetation (B0) as a Function of Distance

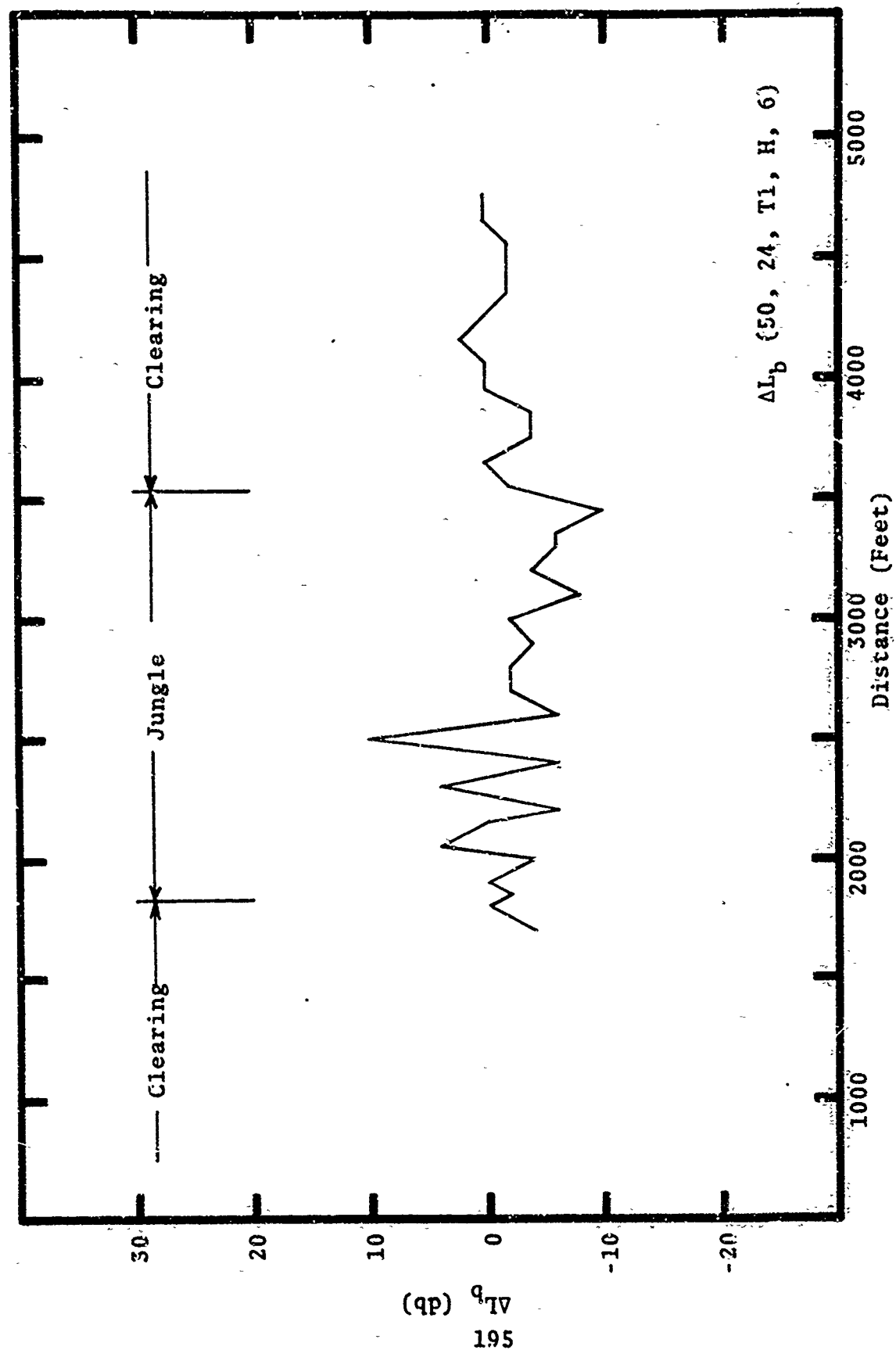


Figure 5.2.52 Basic Transmission Loss Without Vegetation (B8) Minus Loss With Vegetation (B0) as a Function of Distance

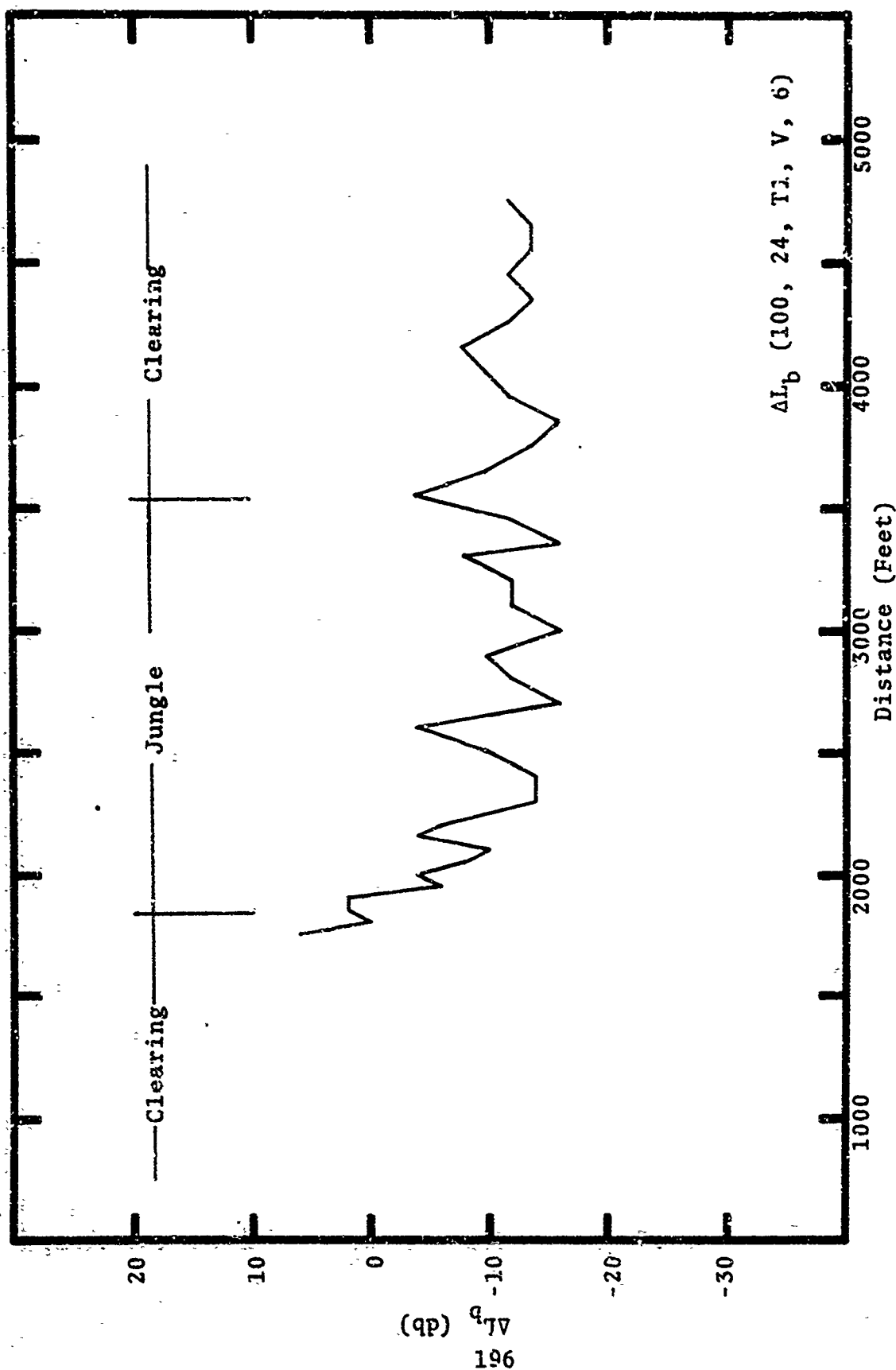


Figure 5.2.53 Basic Transmission Loss Without Vegetation (B8) Minus Loss With Vegetation (B0) as a Function of Distance

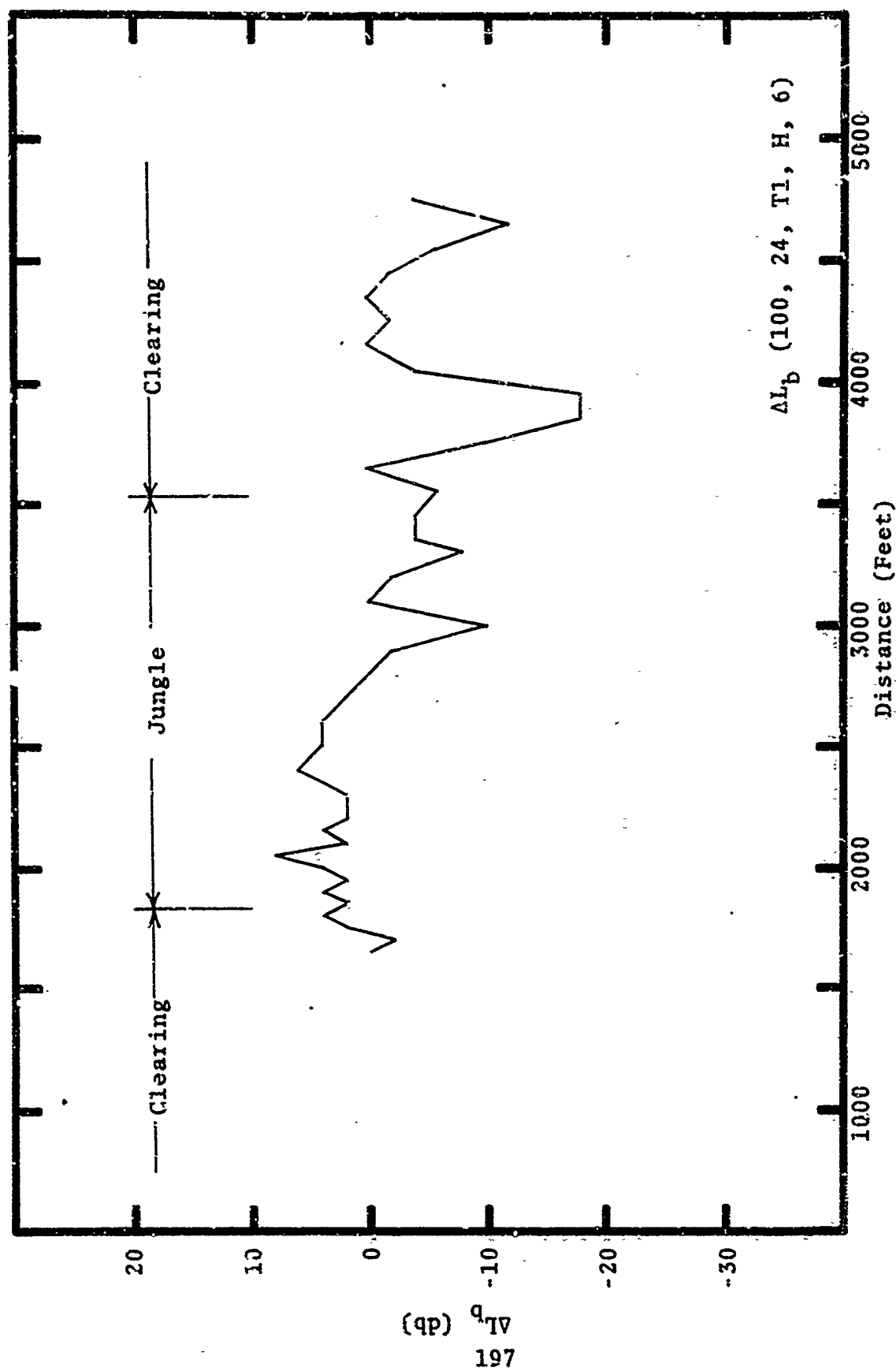


Figure 5.2.54 Basic Transmission Loss Without Vegetation (B8) Minus Loss With Vegetation (B0) as a Function of Distance

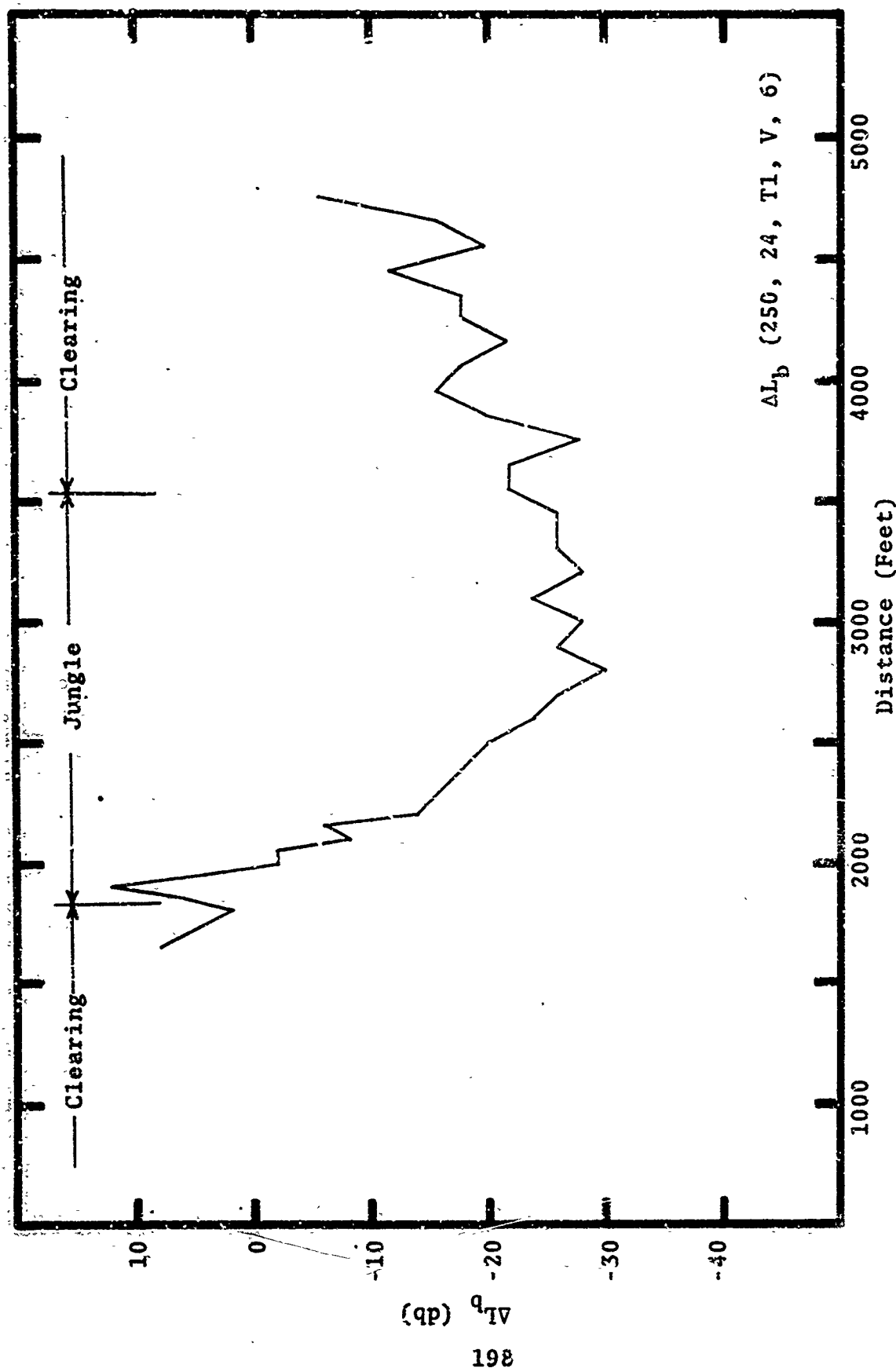


Figure 5.2.55 Basic Transmission Loss Without Vegetation (B8) Minus Loss With Vegetation (B0) as a Function of Distance

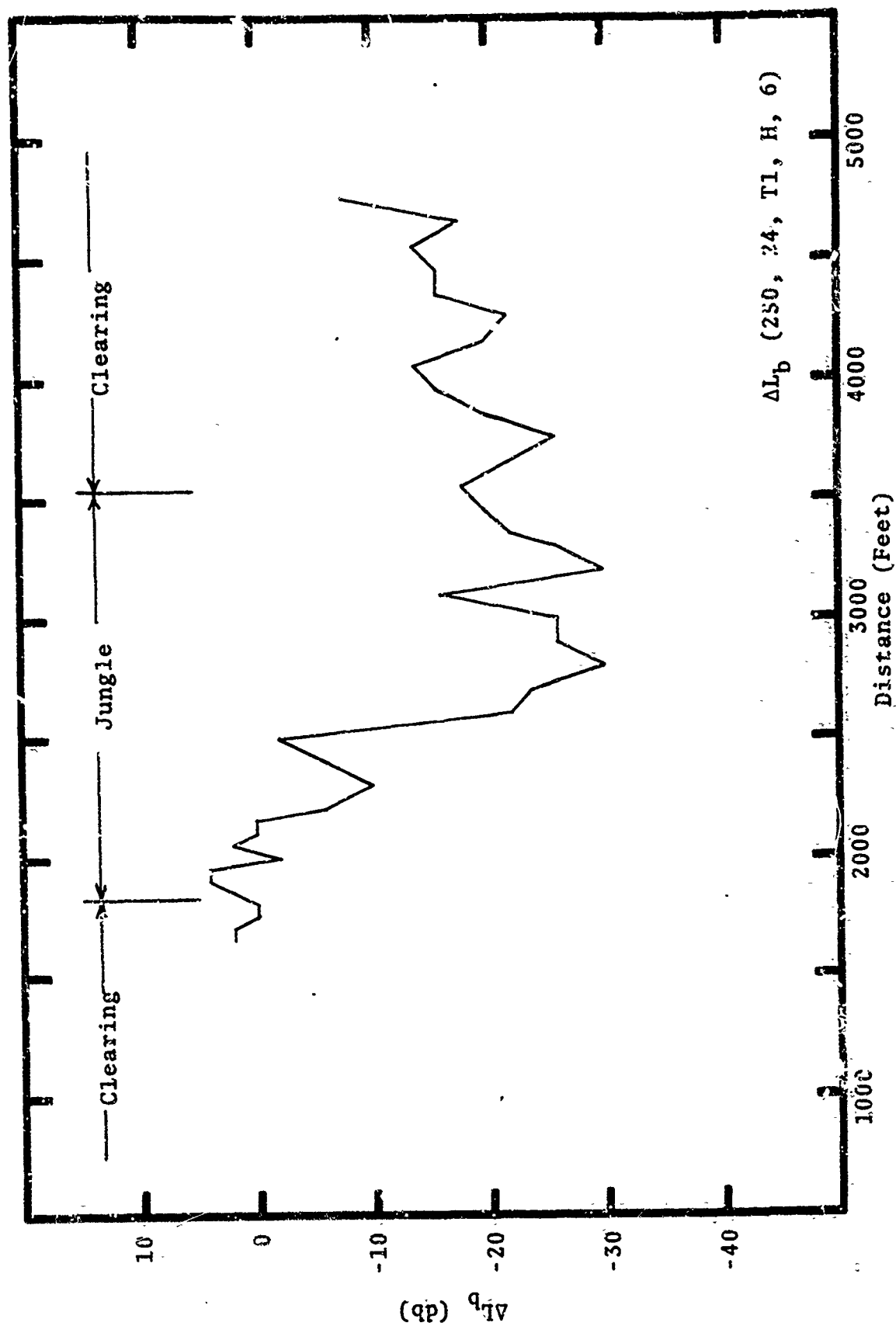


Figure 5.2.56 Basic Transmission Loss without Vegetation (B8) Minus Loss with Vegetation (B0) as a Function of Distance

ΔL_b (dB)

be less for vertical than for horizontal polarization with the polarization preference decreasing as frequency increases. This behavior is qualitatively consistent with the transmission loss in an all-vegetated environment, which suggests that the mode of propagation beyond the transition region is a lateral wave, as is intuitively expected.

It is also interesting to examine the effect of the underbrush on propagation (the small trees with diameters ≤ 2 inches). To do this the measured transmission loss with full vegetation present (e.g., B0) is subtracted from the loss for the same transmitting and receiving set-up with the underbrush removed (e.g., B1). The B0, B1, B4 and B5 configurations with transmitting antennas at positions T1 and T2 and all transmitting antenna heights used were employed. Only the data obtained when the receiver was in those path segments where the underbrush was to be or had been cut are used in this comparison (e.g., approximately the last 400 feet of foliage for B0 - B1). Only the measured minimum L_p are used, due to their lesser variability as discussed above. The transmission loss differences so obtained were averaged for the various transmitter heights and the two path segments examined. The justification for this averaging is that, in this case, each loss difference (at a fixed frequency and polarization) can be presumed to be due only to the cutting of the underbrush and is independent of transmitter height and location.

Figure 5.2.57 is a plot of the averaged differences in transmission loss with and without underbrush as a function of frequency and polarization. The difference is seen to be small, and probably negligible from a practical viewpoint, as might have been expected since the underbrush is a small part of the total vegetation content. The difference is generally

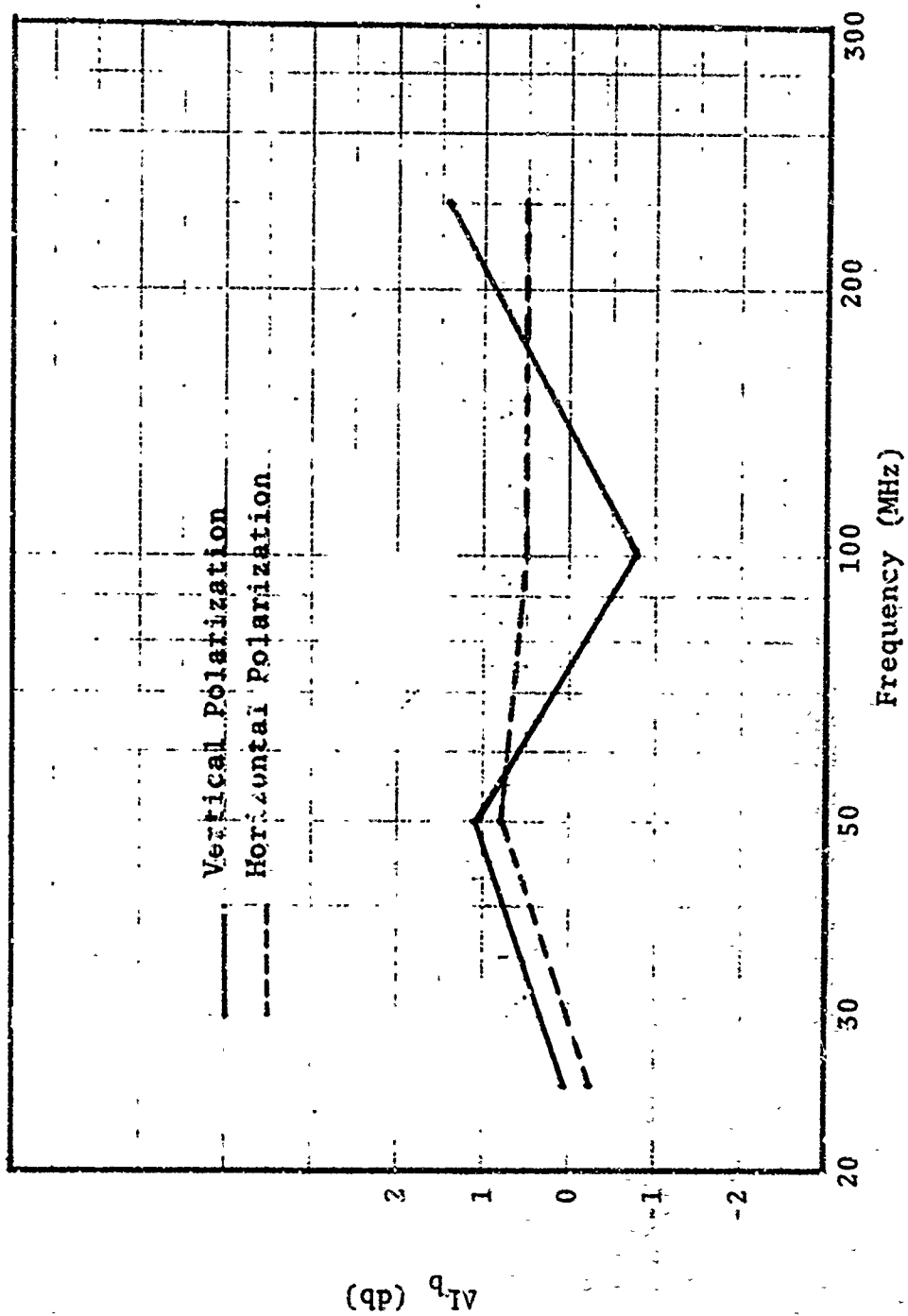


Figure 5.2.57 Average Basic Transmission Loss With Full Vegetation Minus Loss With Underbrush Removed as a Function of Frequency and Polarization

positive, however which is gratifying because it shows that cutting the underbrush, which removes conducting elements from the slab, has the effect of lessening the effective slab conductivity (i.e., decreasing transmission loss) as intuitively expected.

5.3 Conclusions

At frequencies of 25, 50, 100 and 250 MHz, the basic transmission loss tends to increase rapidly over a transition region of a few hundred feet for vertical polarization as the receiver passes from a clearing into vegetation at a height of 6 feet. The transition region increases in length for vertical polarization as the frequency increases. The transition region is not as apparent at the lower VHF frequencies for horizontal polarization as for vertical, but tends to be about the same at the higher VHF frequencies. Beyond this transition region and for both polarizations, the losses generally increase at about the same rate and with the same frequency dependence as a lateral wave in vegetation.

The anisotropy in the forest segment of the mixed paths is similar to that for a completely vegetated path (i.e., there is more loss at vertical than horizontal polarization).

When the receiver moves from vegetation to clearing (with the vegetation between transmitter and receiver) the loss decreases, that is, the signal recovers, within a short distance in a manner similar to diffraction recovery.

The underbrush portion of the foliage has a small effect upon the transmission loss, for the receiving antenna not higher than that of the underbrush, but the loss is generally greater with than without the underbrush.

A theoretical development for the transmission loss in a mixed clearing-vegetation path, which leads to an integral requiring numerical integration, has been given and an analytic approximation to the integral obtained. The theoretical results based on the analytic approximation are in fair agreement with experimental data for horizontal polarization but in poor agreement for vertical polarization. The source of the difference has not been determined, but appears to be in the approximation employed to obtain the analytic solution. The analytical form is not valid and numerical integration of the complete solution appears to be required to determine the validity of the basic theoretical approach developed here for mixed path propagation. But, within the framework of the present program objectives and priorities, it is considered prudent to defer this additional theoretical work to a later time.

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6. SUMMARY OF CONCLUSIONS

Final Reports, Volumes I and II, together summarize the entire experimental and analytical results of path loss measurements in two specifically different tropical jungle areas in Thailand. In Volume I the results of the work in a monsoon tropical, or wet-dry, jungle environment were summarized as a set of hypotheses which generally have now been refined through work in Area II, classified as a rainy tropical jungle.

These two environments have been distinguished from each other essentially in terms of the differences in climate and physical characteristics of the vegetative (jungle) growth. The jungle in Area I has been referred to in these reports as an evergreen, semi-dry, forest. In other literature ^[5] it has also been referred to as semi-evergreen forest which, to some readers, may suggest that there is a degree of seasonal shedding of the leaves, similar to that observed in deciduous forests. However, these two classification terms mean the same thing in relation to the character of the forest in Area I. The forest in this area contains some species of trees of deciduous nature, although these trees do not shed their leaves during the dry season as profusely as a deciduous tree in a temperate zone. The leaves of these trees do turn to a brownish color during the dry season, which suggests less moisture content. The forest of Area I also contains numerous species that do remain green the year around. Hence, the term "semi-evergreen" is an apt descriptor, referring specifically to the character of the forest.

On the other hand, the term "wet-dry evergreen" seems to encompass both the vegetation and the climate. Thus,

in relation to electrogeographical classification systems^[23], this latter descriptor seems more appropriate for the purposes of this project. Such a problem with terminology does not exist with respect to Area II because the forest is much more dominated by evergreen trees, and there is usually little or no dry season to alter the color of the leaves. Thus, the descriptor "tropical rain forest" encompasses both the character of the vegetation and the climate.

On the basis of the annual rate and distribution of rainfall, the distinction between Area I and Area II can be clearly drawn from relatively accurate data. But, with respect to the physical aspects of the vegetation, such a distinction apparently cannot be so clearly drawn. According to forest surveys made in conjunction with the move of the propagation tests from Area I to Area II, it was thought that Area I was characterized by a biomass of about 120 tons per acre, while Area II had about 300 tons per acre. This seemed to correlate with the clearly observable feature of more high trees in Area II than in Area I. Also, Area II contained virgin forest, while Area I is of second growth nature.

But forest survey data recently obtained by Jansky & Bailey, as well as data less recently published^[5], have served to refine the picture insofar as there being a significant and well defined difference in biomass between the two test areas. It is now known that forest surveys based upon small area samples (10 x 40 meters) lead to data having a large variance in biomass and tree height because one or two large trees in each sample area dominate the statistics of the sample, and the question of how many such small sample plots are needed, and how they should be distributed, to correctly characterize a relatively large forest area becomes

highly problematical. A study of these problems has led to the conclusion that the sample plots should be at least 200 x 200 feet for the kind of forests being considered here in relation to radio propagation models. The forest in Area II has been surveyed using 200 x 200-foot sample plots, while all of the data available for Area I^[5,24] were obtained from the smaller sample plot measurements. Taking all of these considerations into account, the best estimate of biomass for Area I is 125 tons per acre, while that of Area II is 165 to 225 tons per acre. The biomass, as well as other statistical parameters, for Area II will be known more definitively when the data from the larger sample plots have been reduced and analyzed.

In addition to biomass, several other statistical parameters have been measured. These include tree heights, diameters at breast height (BHD), nearest neighbor distances (NND), basal area (BA), number of trees per acre (tree density), etc. Among these parameters the upper decile heights of the trees seem to be the most distinctive in comparing Area I with Area II. Surprisingly, the median heights of the trees in the two areas are not greatly different. Also significant is the apparent evidence that the tree density in Area II is generally about the same as that in Area I^[5]. Thus, it can be seen that it is difficult to draw a clear and firm distinction between the forests of the two areas from physical measurements alone.

The purpose of examining the physical aspects of the tropical forests in such detail is to arrive at some methodology with which the different types of vegetation can be classified in terms that can be quantitatively related, or used, in radio propagation models^[23]. Toward this objective,

as described in Section 3, all of the propagation data common to both Area I and Area II have been compared to theoretical results from the slab model, using a fairly large variation in the slab height, H , dielectric constant, ϵ_j , and the conductivity, σ , where, for a given set of comparisons, the dielectric constant and conductivity were held constant, independent of frequency. Time did not permit the incorporation of a suitable, empirically derived, frequency dependency into the computer program for the slab model.

The comparisons have been made generally over the frequency range of 2 to 400 MHz for several combinations of antenna heights, and for both horizontally and vertically polarized transmitting antennas. Best fit over the entire frequency range was obtained with the following parameters:

Area I:

$$\begin{aligned} H &= 60 \text{ feet} \\ \epsilon_j &= 1.01 \\ \sigma_{jH} &= 0.04 \text{ mmhos/meter} \\ \sigma_{jv} &= 0.05 \text{ mmhos/meter} \end{aligned}$$

Area II:

$$\begin{aligned} H &= 100 \text{ feet} \\ \epsilon_j &= 1.01 \\ \sigma_{jH} &= 0.03 \text{ mmhos/meter} \\ \sigma_{jv} &= 0.04 \text{ mmhos/meter} \end{aligned}$$

As has been pointed out in Section 3, the greatest difference between theoretical and experimental values of path loss occurs in the region of 25 MHz and suggests that a better fit could be obtained if the proper frequency dependency is

assigned to the effective dielectric constant and conductivity. However, the fact that the greatest difference between theoretical and experimental values occurs in the lower HF frequency range, with the difference reducing in the upper HF, VHF, and UHF ranges, suggests that the frequency dependency needed for the slab model is not the conventional frequency dependence obtained from measurements in a small volume of vegetated space, such as with open wire transmission line measurements^[22]. Rather, the shape of σ_j versus frequency curve, derived from fitting experimental and theoretical values, appears to be somewhat higher in the region of 25 MHz than the conventional propagation constant approach would suggest. This peculiarity is probably associated with the relation of the median heights of the trees, and the limb elements of vegetation, to the wavelength in this frequency range.

Thus, some fairly important conclusions can be summarized at this point. First, the slab model is a good representation of both the phenomenological and quantitative aspects of propagation in forested environments. This model can be improved by using empirically derived frequency dependent values for the forest conductivity. Based upon the comparisons in Section 3, the appropriate slab height, H , appears to be near the height exceeded by 90 per cent of the trees, rather than the median height previously thought more appropriate. The slab model is very sensitive to the values of σ_j and ϵ_j used in the computation of path loss, and only a very restricted range of values is permissible, in conjunction with H , without giving the wrong values of path loss.

By its nature, the slab model can yield only smoothed data on path loss, and will tell nothing of the

statistical variability in amplitude and phase of the received signal to be expected in a forested environment. To achieve this will require an extension to the slab model to account for the scattering effect of the trees and other obstacles. The slab model is a good point of departure for a scatter model because it can predict very well the smoothed, or average, transmission loss in a forested environment.

Further evidence of the applicability of the slab model is provided in Section 4, which also presents a comparison between theoretical and experimental results. Again, the greatest difference is in the range of 25 MHz (the lowest frequency measured in the air-to-ground work). Perhaps a more significant finding is beginning to emerge by comparing the variability of the signal in the air-to-ground measurements to that in the ground-to-ground measurements. Almost the same amount of variability can be noted. Thus, since the airborne terminal was relatively free of the effects of nearby trees, this comparison suggests what might be an important principle; that is, the variability of the signal is dependent on the end of the link in the worst environment. However, this principle needs further examination before it can be put forth on any firm foundation of evidence.

The third type of path discussed in this report is the so-called "mixed path." In this case, however, it was not possible to compare the experimental data with a complete mathematical solution of the theoretical model. This was because time did not permit a numerical integration of the integral involved. But the comparisons with the simplified mathematical formula are most encouraging, and indicate the possibility that the principles of the slab model can ultimately be applied to the mixed path configuration with

as good agreement as the ground-to-ground path and the air-to-ground path in a tropical forested environment.

Finally, the experimental and theoretical results obtained strongly suggest that the forest biomass is not an important parameter in the use of the slab model for forested environments. Rather, the model is more dependent upon the height exceeded by 90 per cent of the trees, and the number of trees per acre (tree density), than on the other physical parameters of the forest. It may be reasonably conjectured that this situation will also hold in the statistical model obtained by extending the slab model to take into account the scatter process.

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7. APPENDIX

A theoretical approach is developed which gives the basic transmission loss over a mixed vegetation-clearing, or for fully vegetated paths that have a discrete change in electrical height or propagation constant in the path. The results are compared with experimental data in Section 5. The geometry of a mixed clearing-vegetation propagation path is shown in Figure 7.1. The general development is given for a clearing-vegetation path, but it is equally valid for a path containing a transition between two different types of vegetation (i.e., different densities or heights). The transmission loss L_b between transmitter and receiver is defined as [Norton, 1959]

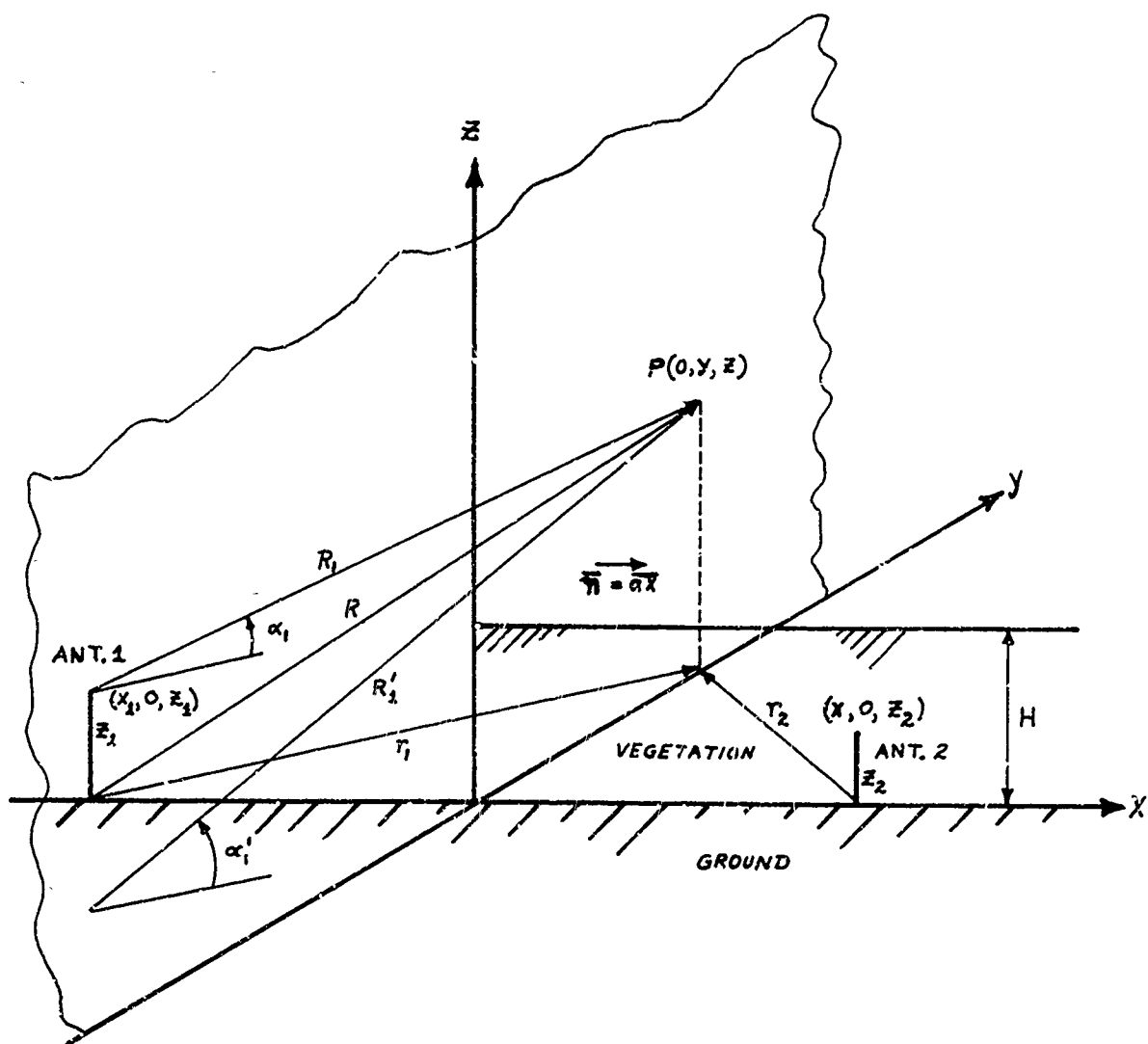
$$L_b \equiv -10 \log \frac{P_r}{P_t} \quad (7.1)$$

where P_r and P_t are the available power at receiver and transmitter, respectively. Ming Kuei Hu [1958] has shown that the power transmission between two isotropic radiators in linear, isotropic media (which is assumed for the mixed path) may be given by a "power reciprocity" expression,

$$\frac{P_r}{P_t} \equiv \frac{P_2}{P_1} = T_{12}^2 = \frac{\left| \int_S (\bar{E}_1 \times \bar{H}_2 - \bar{E}_2 \times \bar{H}_1) \cdot \bar{n} ds \right|^2}{16 P_1 P_2}, \quad (7.2)$$

where S is a surface enclosing one of the sources. The fields \bar{E}_1 , \bar{H}_1 , and \bar{E}_2 , \bar{H}_2 are the fields on S due to the radiated powers P_1 and P_2 at sources 1 and 2, and \bar{n} is the unit outward vector normal to S .

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$$\epsilon_g = 15$$

$$\epsilon_j = 1.01$$

$$0.03 \leq \sigma_{jH} \leq 0.04 \text{ mmhos/meter}$$

$$0.04 \leq \sigma_{jV} \leq 0.05 \text{ mmhos/meter}$$

Figure 7.1 Geometry for Clearing-Vegetation Mixed Path

The problem is general to this point, and substitution of Eq. 7.2 into Eq. 7.1 gives the formal expression for the transmission loss over the mixed path. Of course, effecting this solution requires the fields on the surface, which in turn requires that properties of the path segments be specified. For the general mixed path, it is assumed that the foliage of each path segment can be approximated by a uniform conducting slab having parallel plane surfaces, bounded above by air and below by ground, as proposed by Sachs and Wyatt [1966, 1968]. The properties of the air, vegetation and ground are assumed homogeneous and the slab height constant over each path segment. In general, the ground elevation is permitted to change between segments. However, to avoid the extreme case of mountainous terrain, which would invalidate a later assumption, attention is restricted to a flat ground surface, which is a good approximation to propagation in forested environments over fairly rough terrain [Tamir, 1968].

Attention is restricted to the two-segment clearing-to-vegetation propagation path of Figure 7.1. This will serve as an illustration for solving general mixed foliage and foliage-clearing paths over fairly rough terrain and allows a comparison of the theory with available experimental data.

For vertical polarization, Eq. 7.2 may be written as

$$T_{12}^2 = \frac{\left| \iint_{-\infty}^{\infty} (-E_{z1} H_{y2} + E_{z2} H_{y1}) dy dz \right|^2}{16 P_1 P_2} \quad (7.3)$$

The surface S is taken as the infinite y-z plane separating the two path segments. The fields on S may be

specified by using Kirchhoff's approximation, wherein \bar{E}_1, \bar{H}_1 are the fields at $P(o,y,z)$ on S due to source 1 for the total path assumed to be over plane earth with no vegetation, and \bar{E}_2, \bar{H}_2 are the fields at $P(o,y,z)$ due to source 2 for the total medium assumed to be vegetation, as in medium 2. It is noted that this approximation (which accounts for eliminating mountainous terrain) ignores diffraction over the foliage-clearing interface and reflections from the interface. The two components of electric field at $P(o,y,z)$ then simplify to the well known expressions for a vertical dipole* source at 1 [Jordon, pp 618-635, 1950].

$$E_{z1}(o,y,z) = -ink \frac{Idl}{4\pi} \left[\frac{e^{ikR_1}}{R_1} \cos^2 \alpha + \rho_v \frac{e^{ikR_1'}}{R_1'} \cos^2 \alpha' \right]$$

where $\eta = 120 \pi$, and

(7.4)

$$E_{r1}(o,y,z) = -ink \frac{Idl}{4\pi} \left[\frac{e^{ikR_1}}{R_1} \cos^2 \alpha \tan \alpha + \rho_v \frac{e^{ikR_1'}}{R_1'} \cos^2 \alpha' \tan \alpha' \right]$$

where ρ_v is the ground reflection coefficient for vertical polarization. The lateral wave electric fields due to a small dipole at source 2 is [Tamir, 1967]

* The development is carried out for dipole sources, in accordance with most references, and specialized later to isotropic source to obtain basic transmission loss.

$$E_{z2}(0,y,z) = 60 \text{ Idl } \frac{e^{ikr_2}}{r_2^2 (\eta_j^2 - 1)} F(z_0) F(z)$$

(7.5)

$$E_{r2}(0,y,z) = (\eta_j^2 - 1) E_z(0,y,z)$$

where Idl is the current moment of the sources, z is the variable height on S, and the remaining factors are as defined in Figure 7.1 and Sections 3.1 and 4.1. The absolute value signs of F(z) are removed and the imaginary value of the exponent in F(z) is not effected (i.e., the complex exponent is retained). The remaining fields required in Eq. 7.3 may be determined by Maxwell's equations. The results lead to an expression requiring numerical integration of Eq. (7.3), and further approximations are made here to obtain an approximate analytic solution.

It is assumed that contributions over the surface S are negligible for $z < H$, which permits the integration to be confined to the surface above the jungle. Ignoring contributions over the surface for $z < 0$ (i.e., into the ground) is surely justified and ignoring those through the surface $0 < z < H$ (i.e., directly through the foliage) is justified by experimental evidence for receiving points at $x \geq 0.2$ mi., the distance at which the direct signal through the foliage becomes negligible relative to the lateral wave [Tamir, 1967]. It is further assumed that the sources are far enough from the vegetation-clearing interface to permit plane wave approximations to the

fields on S. Further, neglecting E_r as it is small relative to E_z results in

$$H_{y_1}(0, y, z) = - \frac{x_1}{r_1} \frac{1}{\eta} E_{z_1}(0, y, z)$$

$$H_{y_2}(0, y, z) = \frac{x_2}{r_2} \frac{1}{\eta} E_{z_2}(0, y, z) \quad (7.6)$$

and

$$T_{12}^2 = \frac{\left| \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \left(\frac{x_2}{r_2 \eta} + \frac{x_1}{r_1 \eta} \right) E_{z_1} E_{z_2} dy dz \right|^2}{16 P_1 P_2}$$

Further, taking $\rho_v \approx -1$ and $\cos^2 \alpha \approx 1$, which are considered reasonable approximations for the low antenna heights employed, and relatively high conducting ground of the experimental area,*

$$E_{z_1}(0, y, z) \approx - \eta k \frac{Idl}{2} \frac{e^{ikR}}{R} \sin \frac{kz_1 z}{R} \quad (7.7)$$

Numerical integration is still required, but suppose for the moment that E_{z_1} is the vertical component of the electric field on S (denoted $E_{z_{12}}$) for the dipole at the same position in 1,

* These approximations are made only to simplify the form of the final solution. They are not required to reduce Eq. (7.3) to an analytic result.

but now for an all-vegetative medium, as in medium 2. The same geometrical factor of $x_2/r_2\eta + x_1/r_1\eta$ in the integrand holds, and the power transmission, called T_ℓ^2 , is just the lateral wave power transmission between two antennas for an all vegetative medium (Sections 3.1 and 4.1) and is easily seen to be

$$T_\ell^2 = \left| \frac{2\pi \sqrt{10} E_\ell}{k\eta \sqrt{P_1}} \right|^2$$

or

$$T_\ell^2 = \frac{\left| \iint_S \left(\frac{x_2}{r_2\eta} + \frac{x_1}{r_1\eta} \right) E_{z1\ell} E_{z2} dy dz \right|^2}{16 P_1 P_2} = \left| \frac{2\pi \sqrt{10} E_\ell}{k\eta \sqrt{P_1}} \right|^2 \quad (7.8)$$

where E_ℓ is the corresponding lateral wave field given above. Now, taking the ratio of the vertical electric fields of Eqs. (7.5) and (7.7),

$$\begin{aligned} \frac{E_{z1\ell}(o,y,z)}{E_{z1}(o,y,z)} &= \frac{60 \text{ Idl} \left[e^{ikr_1} \left(\eta_j^2 - 1 \right) r_1^2 \right] F(z_1) F(z)}{-(\eta k/2\pi) \text{ Idl} \left(e^{ikR/R} \right) \sin(kz_1 z/R)} \\ &= \frac{F(z_1) F(z) \text{ Re } e^{ik(r_1 - R)}}{k \sin(kz_1 z/R) r_1^2 (\eta_j^2 - 1)} \end{aligned} \quad (7.9)$$

For small α , $\sin(kz_1 z/R) \approx kz_1 z/R$, and the ratio of $E_{z_1 \ell}/E_{z_1}$ can be seen to vary slowly with y and z relative to the variation of either alone. Hence, making the substitution of

$$E_{z_1 \ell}(o, y, z) = E_{z_1}(o, y, z) \frac{E_{z_1 \ell}(o, y, z)}{E_{z_1}(o, y, z)}$$

in Eq. (7.8), and removing the slowly varying factor $E_{z_1 \ell}/E_{z_1}$ and evaluating it at the stationary phase point $P(o, o, H)$ of E_{ℓ} , one obtains

$$T_{\ell}^2 \approx \left| \frac{E_{z_1 \ell}(z_1, H, x_1)}{E_{z_1}(z_1, H, R)} \right|^2 \frac{\left| \int_{-\infty}^{\infty} \int_H^{\infty} \left(\frac{x_2}{r_2 r} + \frac{x_1}{r_1 \bar{r}} \right) E_{z_1} E_{z_2} dy dz \right|^2}{16 P_1 P_2}$$

or

$$T_{\ell}^2 \approx \left| \frac{E_{z_1 \ell}(z_1, H, x_1)}{E_{z_1}(z_1, H, R)} \right|^2 \left[T_{12}^2(z_1, z_2, x - x_1) \right] \quad (7.10)$$

where the functional dependencies are indicated.

The development has been given for vertically polarized sources. The same relationship applies for horizontal polarization with E_z replaced by E_y , the appropriate lateral wave fields for horizontal polarization (Sections 3.1 and 4.1). Note that the assumption of $\rho_V = \rho_H = -1$ makes the horizontal

and vertical field the same for the space wave. At close ranges, where $\cos^2 \alpha \approx 1$ may not be a good approximation, $\cos^2 \alpha$ may be reinserted in E_{z_1} for vertical polarization but is not a factor in horizontal polarization [Jordon, 1950].

Thus, for isotropic antennas with $\cos^2 \alpha \approx 1$, the final expression is

$$T_{12} \approx \sqrt{3/2} \frac{\left| \sin \left(\frac{kz_1 H}{R} \right) \right| |F(z_2)| x_1^2}{kR(x - x_1)^2 |F(H)|} \quad (7.11)$$

and $L_b = -20 \log T_{12}$.

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